Monitoring Effectiveness of Nonpoint Source Nutrient Management in the North Bosque River Watershed

Final Project Report

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CHAPTER 1

Introduction

This project is a continuance of the microwatershed monitoring in the North Bosque River watershed being used to assess reductions in agricultural nonpoint source (NPS) pollution associated with Implementation Plan (I-Plan) activities for two total maximum daily loads (TMDLs) for the North Bosque River (NBR). The format and analyses in this report largely follows that of previous microwatershed monitoring reports, such as McFarland and Millican (2011) and Millican and McFarland (2008).

The TMDLs for NBR, Segments 1226 (North Bosque River) and 1255 (Upper North Bosque River), were developed in response to impairments based on narrative water quality criteria related to nutrients and excessive growth of aquatic vegetation first noted on the 1998 Texas 303(d) List (Figure 1). Through the TMDL process, phosphorus was identified as the nutrient most often limiting aquatic plant growth, and dairy waste application fields (WAFs) and municipal wastewater treatment facility (WWTF) effluents were considered the major controllable sources of phosphorus to the river. The Texas Commission on Environmental Quality (TCEQ) adopted two TMDLs for phosphorus in the NBR for Segments 1226 and 1255 in February 2001 (TNRCC, 2001). These TMDLs were approved by the United States Environmental Protection Agency (USEPA) in December 2001. An I-Plan for soluble reactive phosphorus (SRP) in the NBR watershed for Segments 1226 and 1255 was approved by the TCEQ in December 2002 and by the TSSWCB in January 2003 (TCEQ and TSSWCB, 2002).

As part of the I-Plan, a microwatershed approach to monitoring was included to provide finer geographic resolution for managing implementation activities (identified as "Tributary Monitoring" in the I-Plan). Monitoring at the microwatershed or subwatershed level allows the impact of agricultural NPS implementation activities to be assessed separately from urban runoff and WWTF contributions. Monitoring at several microwatersheds was initiated in 2001 through TSSWCB projects 01-13 and 01-14, *Technical and Financial Assistance to Dairy Producers and Landowners of the NBR Watershed within the Cross-Timbers and Upper Leon SWCDs*. This monitoring has continued under a series of related projects: TSSWCB project 01-17, *Extending TMDL Efforts in the NBR Watershed,* TSSWCB project 04-12, *Assessment of Springtime Contributions of Nutrients and Bacteria to the NBR Watershed,* TSSWCB project 08-09, *Microwatershed-Based Approach to Monitoring and Assessing Water Quality in the NBR Watershed*, and now under the current TSSWCB project 09-07, *Monitoring Effectiveness of Nonpoint Source Nutrient Management in the North Bosque River Watershed*. While previous projects have supported monitoring at up to 18 microwatershed sites, the current project continued monitoring at 13 of these sites within the upper portion of the NBR watershed from March 2010 through July 2014 (Figure 2). For statistical evaluations of changes in water quality over time, historical data from previous projects supplemented this data set.

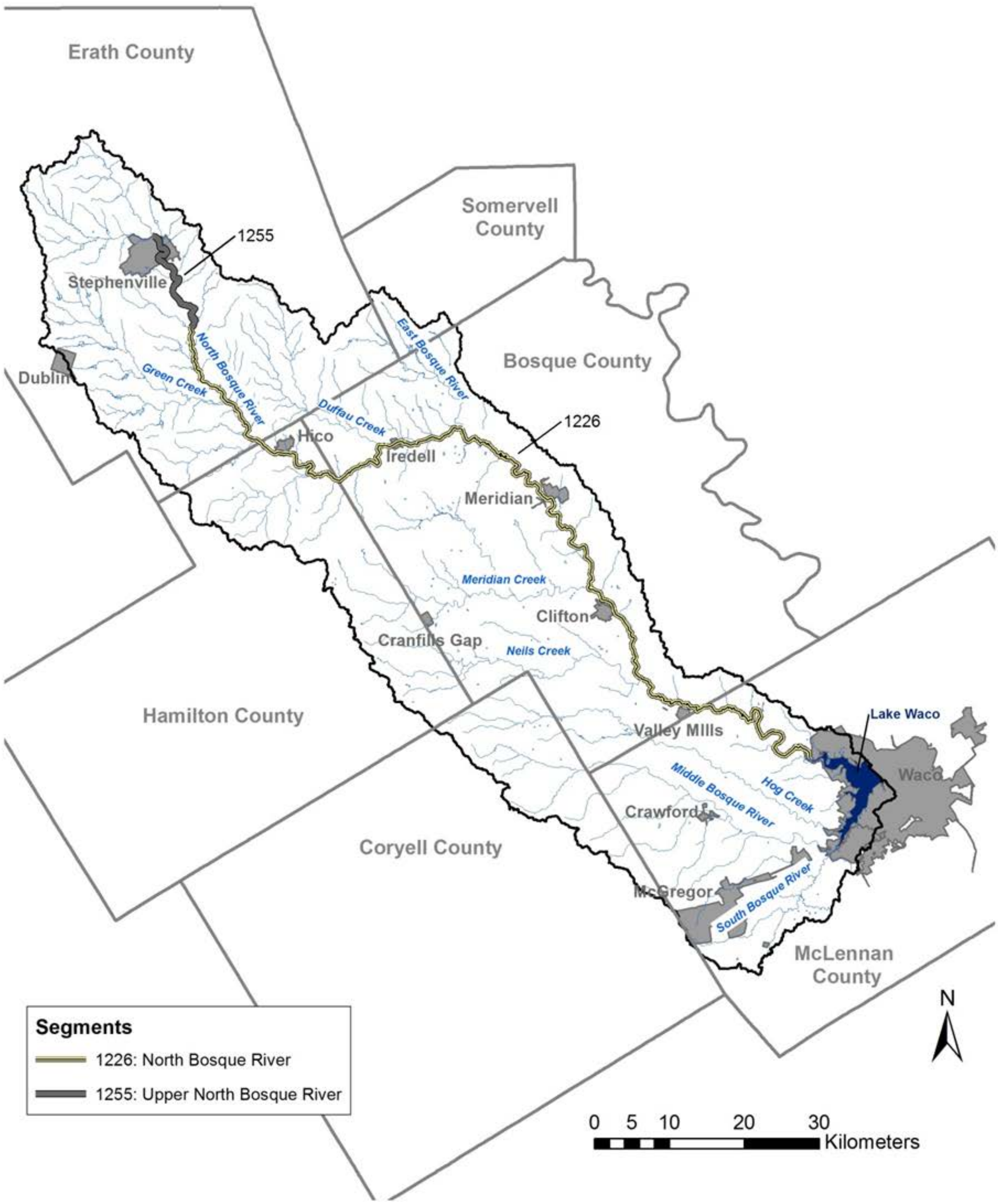

Figure 1 Classified stream segments within the Bosque River watershed.

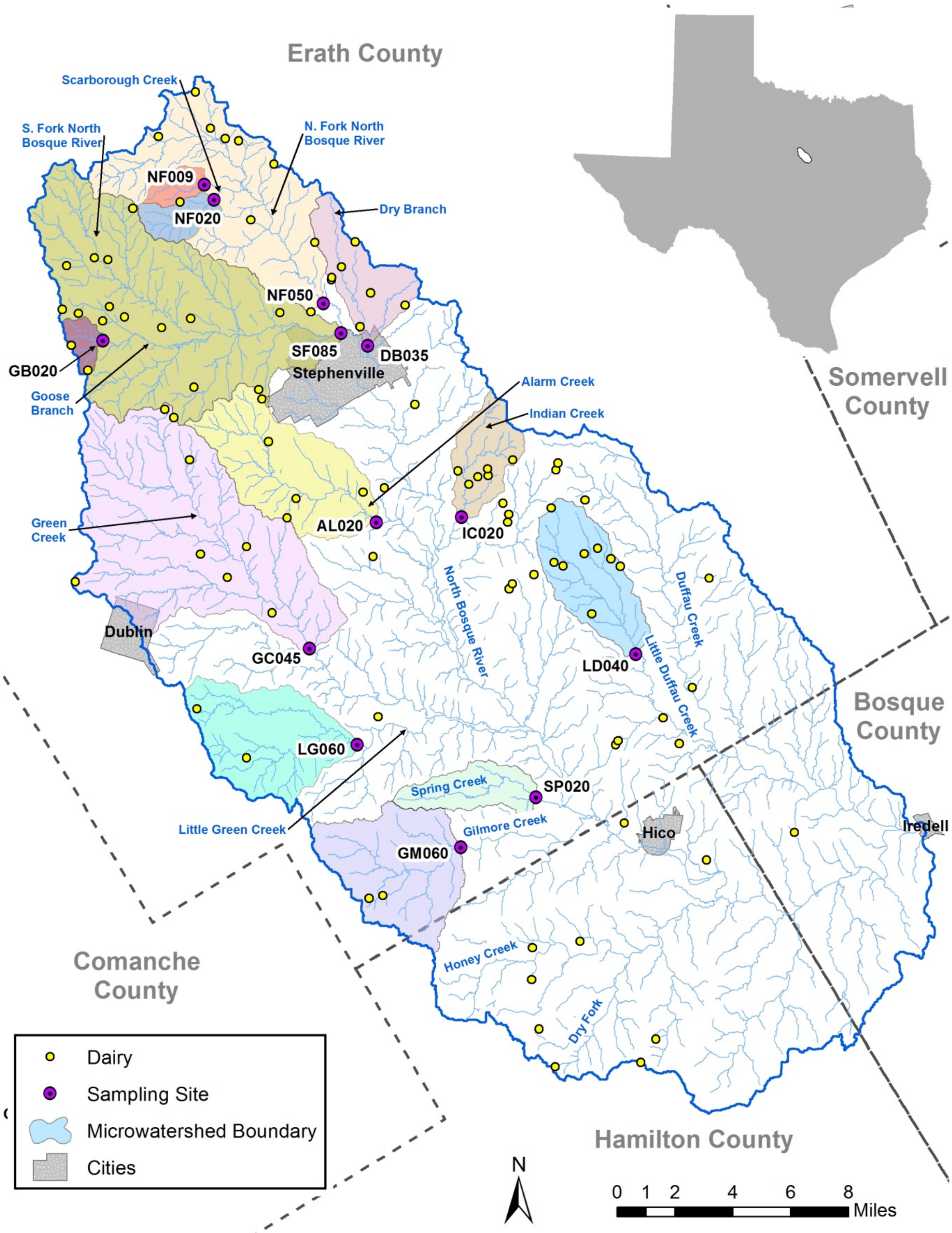

Figure 2 Microwatershed sampling sites and subwatershed delineations. Dairies represent active facilities as of 2001.

Monitoring emphasized sites within the upper portion of the NBR watershed, because most dairy operations are found in this portion of the watershed (Figure 2). The goal of the monitoring is to provide targeted surface water quality data to evaluate the effectiveness of agricultural NPS pollution abatement efforts associated with I-Plan activities for two phosphorus TMDLs in the North Bosque River watershed. Of the four basic elements outlined for phosphorus control in the I-Plan, three focus on nutrient management associated with animal waste. These three elements include:

1. Use of phosphorus application rates for land application of manure,

2. Use of reduced phosphorus in diets of dairy cows to decrease manure phosphorus, and

3. Removal of about half the dairy-generated manure from the watershed.

The fourth element deals with the implementation of phosphorus effluent limits on municipal WWTFs as the major contributing point source.

To address phosphorus application rates on dairy WAFs, the TSSWCB initiated the Comprehensive Nutrient Management Plan (CNMP) Program. The TSSWCB supports the voluntary implementation of CNMPs by dairy producers as part of their water quality management plans (WQMPs) for animal feeding operations (AFOs). In addition to voluntary compliance, the TCEQ amended rules[1] for concentrated animal feeding operations (CAFOs) in 2004 to require permitted dairies in the North Bosque to implement Nutrient Management Plans (NMPs).

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

While there is not a specific program that addresses phosphorus in the diet of dairy cattle, anecdotal evidence from dairy producers supported by local feed specialists and Texas AgriLife Extension Service (formerly Texas Cooperative Extension) indicates that lower phosphorus diets are being fed. In the mid to late 90s, a survey of dairy diet formulations including dairies in the North Bosque River watershed

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

indicated that cow diets averaged 0.52 percent phosphorus (Sansinena et al., 1999). Revised recommendations by the National Research Council (NRC) indicate that about 0.38 percent phosphorus is optimal for high producing dairy cattle (NRC, 2001), which has been supported in various studies to reduce excess phosphorus in manure (e.g., Powel and Satter, 2005; Miller et al., 2010).

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

The success of the manure composting program in reducing instream phosphorus was apparent at stream sites where proportionally larger amounts of dairy manure were hauled to composting facilities (see Bekele et al., 2006 and Millican and McFarland, 2008). The idea behind the CMIP and DMES project was to establish a manure composting industry that would be self-sufficient after the ending of these two incentive programs. Funding for CMIP continued through August 2006, while the DMES project continued to pay incentives to haulers through February 2007. Seven composting facilities were active during these projects, but this number has not been sustained. The number of composting facilities has decreased over the years. As of March 2008, six were still active and receiving dairy manure, but as of 2012, only two composting facilities are still fully operational and one other only sporadically receives manure (TCEQ, 2012a). While the number of composting facilities has declined, composting is still a viable option for dealing with manure waste within the watershed, and indicated as an option for manure disposal as part of the NMP associated with many CAFO permits.

With implementation activities, it is important to monitor and statistically evaluate water quality on a recurring basis to determine if these activities are improving water quality. The I-Plan activities occur over varying timeframes and also vary spatially within the watershed. It is expected that changes in water quality will be gradual and lag actual implementation on the land, particularly with regard to reducing nonpoint source pollutants. It can take several years after implementation occurs before instream improvements become apparent. While some improvements have already been noted in association with the manure haul-off program, additional improvements are anticipated. To evaluate water quality improvements associated with NPS implementation practices, water quality at the 13 microwatershed sites was evaluated for decreases over time in phosphorus parameters (orthophosphate phosphorus [PO_4-P] and total phosphorus [total P]). Changes in concentrations of nitrogen parameters as well as total suspended solids (TSS) were also evaluated. Given the large land areas involved, the number of different land uses, and the spatial and temporal variation in I-Plan activities occurring within each microwatershed, it is not possible to make direct cause and effect linkages, but a weight-of-evidence approach is used to present these results in the context of I-Plan activities.

CHAPTER 2

Site Information

Location and Sampling History

Thirteen sampling sites were associated with the project with historical data extending back to at least 2001 at all stations (Table 1 and Figure 2). All sampling sites were labeled using a five character alphanumeric code. The first two letters specify the tributary or river on which the site was located (e.g., AL for Alarm Creek), while the last three digits indicate the relative location of the site. Lower numeric values indicate sites nearer the headwaters, while larger numeric values indicate sites further downstream on a given creek or stream.

Table 1 Sampling history for monitoring sites in the North Bosque River watershed.

Site	TCEQ ID	Watershed and General Location	Date of First Grab Sample	Date of First Automatic Storm Sample
AL020	17604	Alarm Creek at FM 914	14-May-01	5-Sep-01
DB035	17603	Dry Branch near FM 8	2-Apr-02	5-Feb-02
GB020	17214	Unnamed tributary to Goose Branch between CR 541 and CR 297	11-May-95	5-May-95
GC045	17609	Green Creek upstream of SH 6	16-Apr-01	26-May-01
GM060	17610	Gilmore Creek at bend of CR 293	5-Feb-01	31-Aug-01
IC020	17235	Indian Creek downstream of US 281	8-Jun-94	18-Oct-93[a]
LD040	17608	Little Duffau Creek at FM 1824	14-May-01	31-Aug-01
LG060	17606	Little Green Creek at FM 914	14-May-01	14-Jul-01
NF009	17223	Unnamed tributary of Scarborough Creek at CR 423	18-Apr-91	16-May-92[b]
NF020	17222	North Fork North Bosque River Scarborough Creek at CR 423	30-Oct-91	19-May-92
NF050	17413	North Fork of North Bosque River at SH 108	4-Apr-91	07-Jun-91[c]
SF085	17602	South Fork of North Bosque River at SH 108	30-Apr-01	26-May-01
SP020	17242	Spring Creek at CR 271	8-Jun-94	20-Oct-93[a]

a. Storm sampling suspended March 3, 1998 through May 3, 2001 at IC020 and SP020 .
b. Automated sampler at NF009 was offline from March 25, 1998 through June 12, 1998.
c. Storm sampling at NF050 was suspended from February 9, 1997 through May 1, 2001 and grab sampling suspended May 1997 through April 2001. In April 2001, grab sampling was reinitiated at NF050, but no samples were collected until April 2002 due to dry stream conditions.

Land Use and Drainage Areas

Sampling sites were located primarily in the upper third of the North Bosque River watershed to focus on nonpoint contributions from dairy WAFs. Although WAFs were a focus, sites were chosen to represent the diversity of land uses within the upper portion of the watershed. The land use within microwatersheds ranged from predominately wood and rangeland, as above site GM060 and SP020, to land highly impacted by WAFs, as above GB020 and NF020 (Table 2). Monitoring this diversity of land uses was done to compare the effect of different land uses on water quality.

Table 2 Land use and drainage area information for sampling sites. Land-use information based on classification of satellite imagery from 2001 through 2003 (Narasimhan et al., 2005) and a review of TCEQ records for information on WAFs conducted in 2000 and 2005 (McFarland and Jones, 2006) and updated in 2007 (Houser and Hauck, 2010).

Site	Wood & Range (%)	Pasture (%)	Cropland (%)	Animal Waste App. Fields[a] (%)	Urban or Impervious Surfaces (%)	Other (%)	Total Area (Hectares)
AL020	31.9	45.0	7.8	11.7	2.8	0.8	4,720
DB035	23.3	45.6	11.3	14.3	3.5	2.0	2,130
GB020	25.1	22.6	5.8	40.0	4.7	1.8	440
GC045	31.1	49.1	8.6	7.8	2.4	0.9	11,900
GM060	55.9	35.8	1.1	5.8	1.1	0.3	4,410
IC020	36.7	35.1	6.7	19.3	1.7	0.5	1,740
LD040	33.2	26.9	7.2	31.3	0.3	1.0	2,960
LG060	38.9	40.2	8.6	10.3	1.0	1.0	4,260
NF009	30.8	49.8	2.7	13.5	2.8	0.4	520
NF020	19.6	33.7	2.4	41.3	1.9	1.0	800
NF050	23.4	47.8	7.4	17.7	2.8	0.8	8,370
SF085	28.2	37.7	11.8	16.7	4.5	1.1	12,900
SP020	65.0	33.1	1.3	0.0	0.3	0.2	1,560

a. Animal waste application fields represent estimates from milking operations and non-milking operations.

The base land-use information was provided from a classification of satellite imagery from 2001 through 2003 conducted by the Texas Agricultural Experiment Station (now Texas AgriLife Research) Spatial Sciences Laboratory (Narasimhan et al., 2005). Information on animal waste application fields was compiled by TIAER from review of TCEQ permit information and used to supplement the satellite imagery classification. The location of animal WAFs was determined from detailed information obtained in 2000 from TCEQ records that was updated in 2005. The updated information on WAFs includes milking and non-milking operations, such as beef cattle and calf raising operations, although milking operations represent over 80 percent of the concentrated animal feeding operations (CAFOs) and animal feeding operations (AFOs) in the watershed.

The size of the drainage area above each sampling site was delineated using 30-meter digital elevation models created from United States Geological Survey 1:24,000 topographic maps (Table 2). Drainage areas for sampling sites were calculated using the AVSWAT 2000 extension in ArcView (DiLuzio et al., 2002). Of note, the drainage area values for specific sites may differ some from those in TIAER reports prior to January 2002 because of changes in the GIS system and the calculation method used to determine these areas.

Site Descriptions

Alarm Creek

Site AL020 Site AL020 is located on Alarm Creek at Farm-to-Market (FM) 914, 7.2 kilometers (4.5 miles) south of Stephenville. The dominant land uses above AL020 are improved pasture and wood and range, with a fair amount of land associated with WAFs and cropland.

Dry Branch

Site DB035 Site DB035 is located on Dry Branch near FM 8, about 0.8 kilometers (0.5 miles) upstream of the confluence with the North Bosque River. The dominant land use above DB035 is improved pasture followed by wood and range, WAFs, and cropland.

Goose Branch

Sites GB020 Site GB020 is located in the Goose Branch microwatershed of the South Fork of the North Bosque River, northwest of Stephenville. Dairy WAFs are the predominant land use in the Goose Branch microwatershed. Much of the remaining land area is covered by native range and woodland or improved pasture. GB020 is located on an unnamed road off Erath County Road (CR) 297.

Green Creek

Site GC045 Site GC045 is located on Green Creek, 0.6 km (0.4 miles) upstream of SH 6, 3.3 km (2.0 miles) northwest of Alexander, Texas. The majority of the land above GC045 is improved pasture followed by wood and range.

Gilmore Creek

Site GM060 Site GM060 is located on Gilmore Creek, at the bend of Erath CR 293, approximately 330 meters (0.2 miles) downstream of the confluence with Wolf Prong Creek, north northeast of Carlton, Texas. Land uses above GM060 are predominantly wood and range and improved pasture.

Indian Creek

Site IC020 Site IC020 is located near U.S. Highway 281, on Indian Creek, which discharges into the upper North Bosque River between Stephenville and Hico, Texas. The majority of the land use above IC020 is characterized as wood or range and improved pasture with WAFs comprising a notable amount (almost 20 percent of the drainage area).

Little Duffau Creek

Site LD040 Site LD040 is located on Little Duffau Creek, at FM 1824, 2 km (1.2 miles) west of Duffau in Erath County. The largest land use category above LD040 is wood and range, although almost as much land (about 30 percent of the drainage basin) is associated with WAFs.

Little Green Creek

Site LG060 Site LG060 is located on Little Green Creek, at FM 914, 3.2 kilometers (2.0 miles) south of Alexander. The land use above LG060 is characterized as mostly wood and range and improved pasture with a notable amount of land (about 10 percent) associated with WAFs.

North Fork

Sites NF009 and NF020 Sites NF009 and NF020 are located along tributaries to the North Fork of the North Bosque River. The North Fork joins the South Fork just north of Stephenville to form the North Bosque River. Sites NF009 and NF020 are located on separate tributaries flowing into the same PL-566 reservoir. Site NF020 is located on the Scarborough Creek tributary at CR 423. Site NF009 is located on an unnamed tributary of Scarborough Creek on CR 423. The dominant land use above NF020 is WAFs, while most of the land above NF009 is characterized as improved pasture.

Site NF050 Site NF050 is located on the North Fork of the North Bosque River, at SH 108, approximately 1.6 km (1.0 mile) northwest of Stephenville. The dominant land use above NF050 is permanent pasture followed by wood and range. Waste application fields are prominent above NF050 comprising about 18 percent of the watershed.

South Fork

Site SF085 Site SF085 is located on the South Fork of the North Bosque River, at SH 108, 250 m (820 feet) upstream of the confluence with the North Fork of the North Bosque River, north of Stephenville. The land use above SF085 is mostly improved pasture or wood and range with much of the remaining land area associated with WAFs and cropland.

Spring Creek

Site SP020 Site SP020 is located near CR 271, on Spring Creek, which discharges into the North Bosque River above Hico. Site SP020 is considered one of the least impacted sites within the watershed with most of its land designated as wood and range. Improved pasture does comprise about a third of the SP020 watershed. No animal waste fields are located in this microwatershed.

CHAPTER 3

Methods

Sample Collection and Analysis

The statistical data evaluation included data collected between January 2001 and December 2013. While direct data from this project were collected between March 2010 and December 2013, the statistical evaluation also included data collected prior to this project to allow a longer timeframe for evaluating trends and comparing water quality changes over time with improvement practices. Data collection and laboratory analysis methods were comparable throughout this timeframe to allow for this statistical evaluation. The methods described below present the monitoring and laboratory analyses of direct data collected during this project as outlined in the project Quality Assurance Project Plan, but also note changes in sampling and laboratory analysis methods that have occurred since 2001 as the monitoring program in the North Bosque has evolved under varying projects. Further details on monitoring can also be found in TIAER's semiannual water quality reports for the Bosque River watershed (e.g., Adams and McFarland, 2008 and McFarland and Adams, 2014a).

Storm Samples

Storm sampling was accomplished using an Isco 4230 or 3230 bubbler type flow meter in conjunction with an Isco 3700 or 6712 sampler, both enclosed in a sheet metal shelter. The Isco flow meters operate by measuring the pressure required to force an air bubble through a 3-millimeter (0.125 inch) polypropylene tube, or bubbler line, then recording this pressure as the water level. The Isco flow meters were programmed to record water level or stage and initiate sample retrieval by the Isco 3700 samplers. Marine deep-cycle batteries, charged via solar cells, provided electrical power.

The Isco flow meters initiated preset sampling programs for the Isco samplers when threshold water levels were exceeded. Each flow meter was programmed to record water level at 5-minute intervals and typically actuate the samplers when a designated stream rise, generally 4 to 8 centimeters (0.13 to 0.25 ft) above the bubbler datum, was registered. Once activated the sampler would retrieve one-liter sequential samples. The typical sampling sequence for sites was:

- An initial sample
- Three samples taken at one-hour intervals
- Four samples taken at two-hour intervals

- All remaining samples taken at six-hour intervals

Samples from individual storm events by site were composited on a daily basis using a flow-weighting strategy. The flow-weighting strategy used stage data recorded during a storm, the rating curve developed for each site, and a TIAER-developed computer program. During sample collection, stage data were uploaded from data loggers to portable computers, and then downloaded at TIAER headquarters for use with the computer program. The program reads the stage level associated with the time interval for each sample collected at a site, correlates the stage to flow using the site's rating curve, and calculates the amount of flow associated with each water sample taken during the storm event. For a group of bottles, the program would then designate the amount to be taken from each bottle to compose a one-liter composite based on the relative volume of flow associated with each bottle within the group. This flow-weighting strategy allowed a reduction in sample load without compromising the intended use of the data in determining storm loadings of waterborne constituents and storm-event mean concentrations.

If a site had storm samples prior to development of a rating curve, a relative discharge based on standard hydrologic relationships was calculated as the wetted cross-sectional area of the stream site times the square root of water level for flow-weighting of samples. Stage-discharge relationships were developed for most sites from manual wading-type flow measurements taken at various water level conditions following USGS methods (Buchanan and Somers, 1969). Stage-discharge relationships for stages that permitted safe wading were extrapolated using the cross-sectional area and a least-squares relationship of average stream velocity to the log of water level. At sites LD040 and LG060, samplers and flow meters were located within road culverts. For LD040 and LG060, mathematical fluid mechanics equations were used to estimate flow from culvert flow equations.

If for some reason (i.e., equipment failure) the automated sampler failed to collect samples, a storm grab sample was collected for analysis. If samples could not be flow-weighted because stage data were missing or could not be electronically downloaded at the time samples were retrieved, storm samples were analyzed sequentially.

Of note, on previous projects occurring prior to September 2008; an attempt was made to monitor all storm events at microwatershed sites based on about a 4 cm rise in water level. Starting in September 2008 as a result of decreased funding, only selected events rather than all events were monitored. Due to relatively dry weather conditions in late 2008 through mid-2014, most storm events that occurred were monitored with generally only a few small events missed.

Routine Grab Samples

Routine grab sampling consisted of a single sample taken near the surface at depths of 0.3 m (1 ft) or less depending on total water depth, as recommended in TCEQ surface water quality monitoring procedures (TCEQ, 2003; 2008; 2012b). When routine grab samples were collected, water temperature, DO, pH, and specific conductance (conductivity) were measured in situ with a YSI (multiprobe) field sampling instrument. Because stream sites were generally very shallow and unlikely to stratify, multiprobe readings were taken only at the surface depth corresponding to routine grab samples.

Routine grab sampling at all sites was performed on a biweekly basis prior to September 2008 and on a monthly basis starting in September 2008 through June 2014. Routine grab samples were collected only when flow was present. Samples were not collected at sites that were dry or pooled. Of note, for non-direct data collected prior to October 2003, filtration and preservation other than temperature reduction (placing samples in coolers with ice) was performed in the laboratory. Beginning in October 2003, procedures were changed to allow filtration and acid preservation to occur in the field for grab samples as indicated by TCEQ sample collection methods (TCEQ, 2008).

Routine samples for nutrients and total suspended solids (TSS) were collected in a one-liter plastic bottle. Starting in October 2003, aliquots for analytes requiring field filtration and/or acidification were taken from this bottle after it had been agitated thoroughly to ensure total mixing of sediments. If conditions allowed, samples were filtered through a 0.45 -micron filter using a 50 CC syringe or a filtration flask and pump. An aliquot for NO_2-N+NO_3-N, and NH_3-N was filtered and transferred to an acidified 60-mL plastic bottle, labeled, capped, and shaken to disperse the acid in the sample. An aliquot for PO_4-P analysis was stored in the syringe if used or in a separate bottle, which was then labeled and iced for submittal to the lab. An aliquot for TP and TKN analysis was poured from the liter bottle into a labeled and acidified 250-mL plastic bottle, which was capped and shaken to disperse the acid. The remaining sample (about 500 mL) was submitted to the lab for TSS analysis. Of note, if samples were too turbid to reasonably field filter, a comment was added to the chain of custody form and aliquots associated with constituents requiring filtration were kept in the one-liter bottle for filtration and acidification by the lab.

In addition to nutrient and TSS constituents, routine grab samples were analyzed for *Escherichia coli* (*E. coli*) bacteria. Samples for bacteria analysis were collected in sterile plastic 250-mL bottles that had been autoclaved and sealed with autoclave tape. Bottles used for bacteria samples included an addition of 10 percent sodium thiosulfate to minimize the impact of potential chlorine residuals. Of note, grab samples prior to April 2004 were analyzed for *E. coli* and/or fecal coliform (FC).

Parameters and Analysis Methods

Ammonia-nitrogen (NH_3-N), nitrite-nitrogen plus nitrate-nitrogen (NO_2-N+NO_3-N), total Kjeldahl nitrogen (TKN), PO_4-P, total-P (total P), and total suspended solids (TSS) were evaluated from routine grab and storm samples (Table 3). In non-direct data collected prior to April 2004, fecal coliform (FC) and/or *E. coli* were analyzed with grab samples. From April 2002 through March 2004, both FC and *E. coli* were analyzed with grab samples using plating techniques. Both FC and *E. coli* were analyzed, because TCEQ was in the process of changing water quality criteria for bacteria from FC to *E. coli* (TNRCC, 2000). In April 2004, FC was discontinued, and the analysis method for *E. coli* was changed to the IDEXX Colilert method. For reference, a comparison paired FC and *E. coli* collected between November 2000 through March 2004 for sampling sites throughout the North Bosque River watershed is presented in McFarland and Millican (2011).

Table 3 Analysis methods and reporting limits for water quality constituents

Constituent	Abbreviation	Method	Range of TCEQ AWRLs or Project LOQs[a]
Field Measurements [b]			
Specific conductance	Conductivity	EPA[c] 120.1	not applicable
Dissolved oxygen	DO	EPA 360.1	not applicable
pH	pH	EPA 150.1	not applicable
Water temperature	Water temp.	EPA 170.1	not applicable
Laboratory Measurements			
Ammonia-nitrogen (dissolved)	NH_3-N	EPA 350.1 or SM[d] 4500-NH3 G	0.02 - 0.1 mg/L
Escherichia coli	*E. coli*	IDEXX Colilert[e]	1 colonies/100 mL
Nitrite-nitrogen+nitrate-nitrogen	NO_2-N+NO_3-N	EPA 353.2 or SM 4500-NO3 F	0.04 - 0.05 mg/L
Total Kjeldahl nitrogen	TKN	EPA 351.2 or SM 4500-NH3 G	0.20 mg/L
Orthophosphate-phosphorus	PO_4-P	EPA 365.2 or SM 4500P-E	0.005 mg/L[f]
Total phosphorus	Total P	EPA 365.4	0.06 mg/L
Total suspended solids	TSS	EPA 160.2 or SM 2540 D	4 mg/L

a. Source: *Appendix D, Surface Water Quality Monitoring Procedures Manual, Volume 1* (TCEQ, 2003; 2008; 2012b) and listing of *Ambient Water Quality Reporting Limits (AWRLs) for Texas Surface Water Quality Monitoring Programs* (TCEQ, 2012c). If the project LOQ is lower than the program AWRL, then the project LOQ is presented.

b. All field activities follow guidelines as outlined in the applicable version of TCEQ's *Surface Water Quality Monitoring Procedures Manual* (e.g., TCEQ, 2003; 2008; 2012b).

c. EPA refers to *Methods for Chemical Analysis of Water and Wastes* (EPA, 1983).

d. SM refers to the *Standard Methods for the Examination of Water and Wastewater*, 18th Edition (APHA, 1992) or most recent online edition.

e. Results from the IDEXX method are generally reported MPN/100 mL whereas plating technique results are reported as colonies/100 mL. In this report, data for all *E. coli* results using IDEXX are presented in units of colonies/100 mL for consistency with units used by TCEQ. For assessment purposes, MPN/100 mL and colonies/100 mL for *E. coli* are considered equivalent.

f. For PO_4-P the AWRL is 0.04 mg/L, but for the Bosque River a reporting limit of 0.005 mg/L has been established for TCEQ projects due to the TMDLs for soluble reactive phosphorus for Segments 1226 and 1255.

Reporting limits for the data presented are based on ambient water reporting limits (AWRLs) set by TCEQ (TCEQ, 2012c) or project specific limits of quantitation (LOQs). In most cases, the AWRL and LOQ are the same, unless the project requires a lower LOQ, such as for PO_4-P in the NBR watershed. The LOQ for PO_4-P is set at 0.005 mg/L, well below the AWRL of 0.04 mg/L set by TCEQ, due to the lower target concentrations noted in the TMDLs for the NBR (TNRCC, 2001). Left censored data indicated as below the reporting limit (RL) were entered into the database as one-half the RL following recommendations by Gilliom and Helsel (1986) and Ward et al. (1988). For data with a range of RLs, the highest laboratory RL was used to censor the data prior to statistical evaluation.

Statistical Evaluation

Basic Site Statistics

To evaluate conditions at individual microwatershed sites, basic summary statistics including mean, median, and standard deviation were calculated for routine grab samples and event mean concentrations (EMCs) of storm events. Event mean concentrations were calculated for each storm by accumulating the mass via rectangular integration using a midpoint rule to associate concentration with streamflow (Stein, 1977). Instantaneous 5-minute stage readings were used as the minimum measurement interval to indicate flow in cubic feet per second (cfs) and multiplied by 300 seconds to obtain flow for each 5-minute interval. The flow associated with each 5-minute interval was multiplied by the associated water quality concentration and summed across the event to calculate the total constituent loadings. Total constituent loadings were divided by total storm volume to calculate EMCs. These basic statistics were based on data collected from January 2001 through December 2013 as representative of a period after initiation of the I-Plan for the North Bosque TMDLs.

Trend Analysis

Because these microwatershed sites were highly intermittent with flow generally occurring only during or shortly after storm events, trend analyses were not conducted on routine grab samples. Routine grab samples often represented less than 50 percent of the total potential samples at a site leading to long gaps in the sampling history as encountered conditions were often dry or pooled (see Adams and McFarland, 2008 and McFarland and Adams, 2014a for a time history of routine grab sampling at each site).

To evaluate post-TMDL trends at these microwatershed sites, trend analyses were performed on volume-weighted storm event data summarized on a monthly basis for data collected between 2001 and 2013. To calculate concentrations on a monthly basis for trend analysis, the estimated volume and nutrient loadings for all storm events occurring within a given month and year at a site were summed and loadings were divided by the total storm volume to obtain a monthly volume-weighted concentration. The monthly data were evaluated by constituent for seasonality, which was not apparent. The monthly data were, thus, aggregated by year and evaluated for trends using the nonparametric Kendall's tau test statistic as described by Reckhow et al. (1993). The Kendall's tau test was used to evaluate for trends, because it is suitable for water quality data that show non-normal distributions, contain missing data, and contain censored values below method detection or reporting limits (Gilbert, 1987; Hirsch and Slack, 1984).

To minimize problems associated with varying reporting limits over time, the maximum reporting limit was identified for each site by constituent. For consistency, all values in the database below half the maximum reporting limit were set equal to half the maximum reporting limit. Stream flow has also been found to have a distinct impact on water quality concentrations with concentrations often increasing in relation to flow when nonpoint sources are dominant (Helsel and Hirsch, 2002). Using monthly total storm volume as an indicator of flow, data were flow adjusted between months prior to trend analysis following procedures outlined by Helsel and Hirsch (2002) with flow as an ancillary variable.

The Kendall's tau test for trends is based on the rank order of the data. Data are ordered according to year and comparisons are made between data-pair concentrations at year = t and year = t + 1. 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 a the same frequency, no trend exists. The null hypothesis tested was that there was no temporal trend in concentration of water quality constituents. The slope calculated gives the magnitude of the trend and is interpreted as the change in concentration per year on a natural log scale. The slope in original units was computed from the slope on the natural log scale as follows (Helsel and Hirsch, 2002):

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

Where "e" is the base of the natural logarithm, which approximately equals 2.7183; and "b" is the slope for the natural log transformed data. The level of significance used to test the null hypothesis was 0.05.

CHAPTER 4

Results and Discussion

Basic summary statistics for routine grab data are presented in Appendix A and for EMCs from storm events in Appendix B. Stream flow is presented in Appendix C.

Trend Analysis Results

Trend analyses on volume-weighted storm samples collected from 2001 through 2013 indicated several significant trends in water quality (Tables 4-9). Downward trends in PO_4-P were indicated at sites GB020, GM060, and IC020 and increasing trends at sites LD040, NF009, and SF085 (Table 4). For total-P, downward trends were indicated at sites GB020, IC020, and NF020 and increasing trends at sites NF009 and SF085 (Table 5). Decreasing trends in NH_3-N were indicated at sites DB035, IC020, and LG060 (Table 6). Decreasing trends in NO_2-N+NO_3-N were detected at sites GC045 and LG060 (Table 7). Decreasing trends in TKN were indicated at sites IC020 and NF020 and increasing trends at sites SF085 and SP020 (Table 8). Decreasing trends in TSS were indicated at site DB035 and increasing trends at GM060, NF009, NF050, SF085, and SP020 (Table 9).

Table 4 Trend results for monthly volume-weighted PO_4-P data. Data transformed using a natural log transformation and adjusted for flow prior to trend analysis. The p-value indicates the probability of significance. ** indicates statistical significance at a p-value of 0.01, and * indicates significance at a p-value of 0.05.

Site	Period Evaluated	Kendall Test Statistic	p-value	Statistical Significance	Slope (% change/yr)
AL020	Sep 2001 - Dec 2013	-0.0801	0.3409		
DB035	Feb 2002 - Dec 2013	0.1077	0.1793		
GB020	Jan 2001 - Dec 2013	-0.2675	0.0058	**	-4.1
GC045	May 2001 - Dec 2013	0.0123	0.8988		
GM060	Aug 2001 - Dec 2013	-0.1777	0.0475	*	-17.6
IC020	May 2001 - Dec 2013	-0.2862	0.0006	**	-5.9
LD040	Aug 2001 - Dec 2013	0.2299	0.0110	*	3.8
LG060	Jul 2001 - Dec 2013	-0.1395	0.1600		
NF009	Jan 2001 - Dec 2013	0.2024	0.0149	*	3.4
NF020	Feb 2001 - Dec 2013	-0.1130	0.1852		
NF050	May 2001 - Dec 2013	0.0443	0.5910		
SF085	May 2001 - Dec 2013	0.1635	0.0084	**	2.5
SP020	May 2001 - Dec 2013	0.1138	0.1787		

Table 5 Trend results for monthly volume-weighted total-P data. Data transformed using a natural log transformation and adjusted for flow prior to trend analysis. The p-value indicates the probability of significance. ** indicates statistical significance at a p-value of 0.01, and * indicates significance at a p-value of 0.05.

Site	Period Evaluated	Kendall Test Statistic	p-value	Statistical Significance	Slope (% change/yr)
AL020	Sep 2001 - Dec 2013	-0.1352	0.1068		
DB035	Feb 2002 - Dec 2013	-0.1180	0.1411		
GB020	Jan 2001 - Dec 2013	-0.2188	0.0239	*	-3.3
GC045	May 2001 - Dec 2013	0.0058	0.9549		
GM060	Aug 2001 - Dec 2013	-0.1666	0.0633		
IC020	May 2001 - Dec 2013	-0.3968	0.0000	**	-6.8
LD040	Aug 2001 - Dec 2013	0.1479	0.0993		
LG060	Jul 2001 - Dec 2013	-0.1684	0.0895		
NF009	Jan 2001 - Dec 2013	0.2134	0.0102	*	3.9
NF020	Feb 2001 - Dec 2013	-0.2712	0.0014	**	-6.0
NF050	May 2001 - Dec 2013	0.0832	0.3106		
SF085	May 2001 - Dec 2013	0.1796	0.0038	**	3.1
SP020	May 2001 - Dec 2013	0.1506	0.0748		

Table 6 Trend results for monthly volume-weighted NH_3-N data. Data transformed using a natural log transformation and adjusted for flow prior to trend analysis. The p-value indicates the probability of significance. ** indicates statistical significance at a p-value of 0.01, and * indicates significance at a p-value of 0.05.

Site	Period Evaluated	Kendall Test Statistic	p-value	Statistical Significance	Slope (% change/yr)
AL020	Sep 2001 - Dec 2013	0.1294	0.1230		
DB035	Feb 2002 - Dec 2013	-0.2108	0.0084	**	-5.7
GB020	Jan 2001 - Dec 2013	0.0322	0.7453		
GC045	May 2001 - Dec 2013	-0.0792	0.3925		
GM060	Aug 2001 - Dec 2013	-0.0777	0.3880		
IC020	May 2001 - Dec 2013	-0.2814	0.0007	**	-9.4
LD040	Aug 2001 - Dec 2013	0.0532	0.5562		
LG060	Jul 2001 - Dec 2013	-0.1973	0.0464	*	-6.1
NF009	Jan 2001 - Dec 2013	-0.0097	0.9115		
NF020	Feb 2001 - Dec 2013	-0.0995	0.2435		
NF050	May 2001 - Dec 2013	-0.1143	0.1633		
SF085	May 2001 - Dec 2013	0.0843	0.1746		
SP020	May 2001 - Dec 2013	-0.1007	0.2340		

Table 7 Trend results for monthly volume-weighted NO_2-N+NO_3-N data. Data transformed using a natural log transformation and adjusted for flow prior to trend analysis. The p-value indicates the probability of significance. ** indicates statistical significance at a p-value of 0.01, and * indicates significance at a p-value of 0.05.

Site	Period Evaluated	Kendall Test Statistic	p-value	Statistical Significance	Slope (% change/yr)
AL020	Sep 2001 - Dec 2013	-0.0624	0.4585		
DB035	Feb 2002 - Dec 2013	0.0205	0.8007		
GB020	Jan 2001 - Dec 2013	-0.1247	0.1994		
GC045	May 2001 - Dec 2013	-0.2104	0.0224	*	-9.0
GM060	Aug 2001 - Dec 2013	-0.0012	0.9948		
IC020	May 2001 - Dec 2013	-0.1378	0.0976		
LD040	Aug 2001 - Dec 2013	0.0637	0.4800		
LG060	Jul 2001 - Dec 2013	-0.2585	0.0090	**	-7.8
NF009	Jan 2001 - Dec 2013	0.0812	0.3301		
NF020	Feb 2001 - Dec 2013	-0.1639	0.0542		
NF050	May 2001 - Dec 2013	0.0377	0.6482		
SF085	May 2001 - Dec 2013	0.0467	0.4526		
SP020	May 2001 - Dec 2013	0.1012	0.2319		

Table 8 Trend results for monthly volume-weighted TKN data. Data transformed using a natural log transformation and adjusted for flow prior to trend analysis. The p-value indicates the probability of significance. ** indicates statistical significance at a p-value of 0.01, and * indicates significance at a p-value of 0.05.

Site	Period Evaluated	Kendall Test Statistic	p-value	Statistical Significance	Slope (% change/yr)
AL020	Sep 2001 - Dec 2013	-0.0348	0.6809		
DB035	Feb 2002 - Dec 2013	-0.1564	0.0509		
GB020	Jan 2001 - Dec 2013	0.0353	0.7208		
GC045	May 2001 - Dec 2013	-0.0435	0.6409		
GM060	Aug 2001 - Dec 2013	-0.0164	0.8599		
IC020	May 2001 - Dec 2013	-0.4394	0.0000	**	-7.9
LD040	Aug 2001 - Dec 2013	0.0000	1.0000		
LG060	Jul 2001 - Dec 2013	-0.1803	0.0689		
NF009	Jan 2001 - Dec 2013	0.1308	0.1159		
NF020	Feb 2001 - Dec 2013	-0.2322	0.0064	**	-4.7
NF050	May 2001 - Dec 2013	0.0894	0.2757		
SF085	May 2001 - Dec 2013	0.1434	0.0209	*	3.3
SP020	May 2001 - Dec 2013	0.1870	0.0269	*	6.4

Table 9 Trend results for monthly volume-weighted TSS data. Data transformed using a natural log transformation and adjusted for flow prior to trend analysis. The p-value indicates the probability of significance. ** indicates statistical significance at a p-value of 0.01, and * indicates significance at a p-value of 0.05.

Site	Period Evaluated	Kendall Test Statistic	p-value	Statistical Significance	Slope (% change/yr)
AL020	Sep 2001 - Dec 2013	-0.0706	0.4016		
DB035	Feb 2002 - Dec 2013	-0.2287	0.0043	**	-9.1
GB020	Jan 2001 - Dec 2013	0.1812	0.0617		
GC045	May 2001 - Dec 2013	0.1130	0.2215		
GM060	Aug 2001 - Dec 2013	0.2239	0.0125	*	30.8
IC020	May 2001 - Dec 2013	-0.1436	0.0844		
LD040	Aug 2001 - Dec 2013	-0.0450	0.6192		
LG060	Jul 2001 - Dec 2013	-0.1786	0.0716		
NF009	Jan 2001 - Dec 2013	0.2371	0.0043	**	9.1
NF020	Feb 2001 - Dec 2013	-0.1639	0.0542		
NF050	May 2001 - Dec 2013	0.1648	0.0441	*	8.8
SF085	May 2001 - Dec 2013	0.2658	0.0000	**	12.5
SP020	May 2001 - Dec 2013	0.1842	0.0292	*	13.4

Trend results for data through 2013 were compared to results reported in McFarland and Millican (2011), which evaluated data through 2009. For phosphorus constituents, trend results were fairly comparable between the two time periods. Of the four sites showing negative trends with PO_4-P or total-P (GB020, GM060, IC020, and NF020), all but GB020 had previously indicated negative trends. Of the three sites showing positive trends for PO_4-P or total-P (LD040, NF009, and SF085) for data evaluated through 2009, similar positive trends were noted for data through 2013. The slopes indicating the percent change per year were also comparable for all but site GM060. At site GM060, the slope for PO_4-P decreased notably from -43.3% change/yr for data through 2009 to -17.6% change/yr for data through 2013, indicating a larger decrease in earlier years that has now leveled off over time.

For nitrogen constituents, more variability was indicated in trends evaluated through 2009 compared to 2013, particularly for NO_2-N+NO_3-N. Of the three sites (DB035, IC020, and LG060) indicating significant decreasing trends in NH_3-N for data through 2013, only site IC020 also showed decreasing trends when data were evaluated through 2009. One site, NF020, previously showed significant decreases in NH_3-N for data through 2009, but increases in storm NH_3-N concentrations in more recent years have suspended this trend. For NO_2-N+NO_3-N, the two sites (GC045 and LG060) showing negative trends for data through 2013 showed no significant trends when evaluated earlier for data through 2009. In contrast, several sites (GM060, IC020, NF020, and SP020) showed significant negative trends and site NF009 showed a significant positive trend for NO_2-N+NO_3-N when data were previously evaluated through 2009. Of note, several of these previously significant trends for NO_2-N+NO_3-N were only marginally significant (p-value less than 0.05 but greater than 0.01). For TKN, the negative trends noted at sites IC020 and NF020 were similar for both time periods. The positive trends for TKN noted at sites SF085 and SP020 for data through 2013 were insignificant for data through 2009. Of note, a highly significant negative trend for TKN was noted previously at site GM060 for data through 2009 that was not significant when data were evaluated through 2013. A significant increasing trend in TSS was noted at site GM060 for data through 2013, which corresponded with an increase in TKN in recent years, negating the previous negative trend in TKN.

For TSS, similar increasing trends were indicated at sites NF009 and SF085 and a decreasing trend at site DB035 in 2013 was found for data through 2009. In contrast, three sites (GM060, NF050, and SP020) showed significant increasing trends in TSS that were previously insignificant. Also, previously site NF020 had indicated a negative trend in TSS for data through 2009 that was insignificant when data were evaluated through 2013.

Trend Analysis Discussion

Changes in trends over time, as noted above for data through 2009 and 2013, often reflects changing weather conditions. Although trend evaluations were done in a manner to try to adjust for differences in flow over time, weather conditions still play a large role in resulting trends as rainfall-runoff is key in the movement of nonpoint source pollution. Annual rainfall has varied greatly from year to year (Figure 3) as well as the associated runoff in the watershed (Figures 4 and 5). Using 2001 as a cutoff based on when the I-Plan was approved, precipitation and runoff appears less variable during the pre than post-TMDL period, although both periods have obvious years of drought (e.g., years 1999 and 2005) and flooding (e.g., years 1997 and 2007).

While annual precipitation records as shown in Figure 3 indicate near normal rainfall conditions in most years for Stephenville, Texas; these represent only a single point within the watershed. The Palmer Drought Index indicates drought conditions for 2006, 2009, and 2011 through 2013 based on July conditions for the watershed area (NCDC, 2014b). Hydrologically, the watershed response has shown quite low flows in several years (Figures 4 and 5). Drought conditions, which have impacted most of Texas since 2010, have affected the North Bosque River with particularly low streamflow occurring in years 2006, 2011, and 2013 (Figure 5). The timing of rainfall as well as the total amount, thus, greatly influences streamflow. The cumulative monthly rainfall deficit from January 2010 through July 2014 shows this variability and indicates continuing drought conditions from 2013 into 2014 (Figure 6).

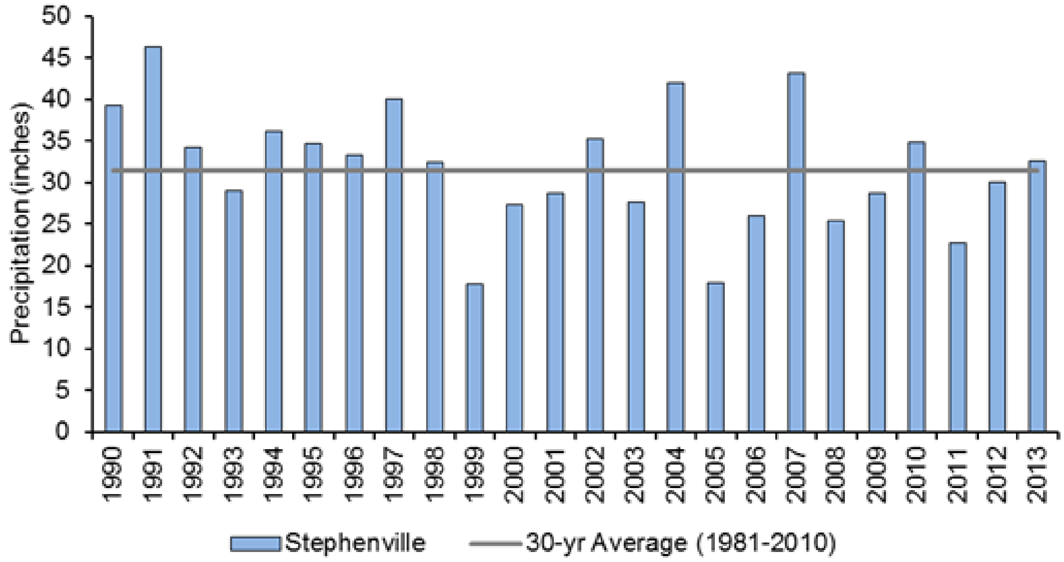

Figure 3 Annual precipitation at Stephenville, Texas. Source: National Climatic Data Center (NCDC, 2014a).

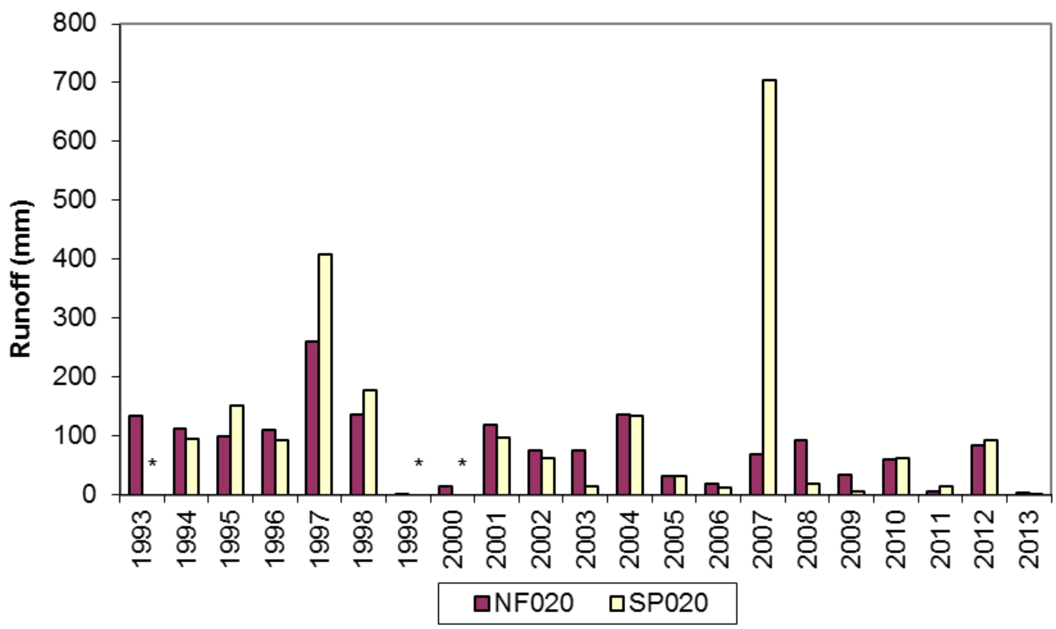

Figure 4 Estimated annual runoff associated with sites NF020 and SP020. Asterisks for SP020 in 1993, 1999 and 2000 indicate years with incomplete data, thus, no annual value presented.

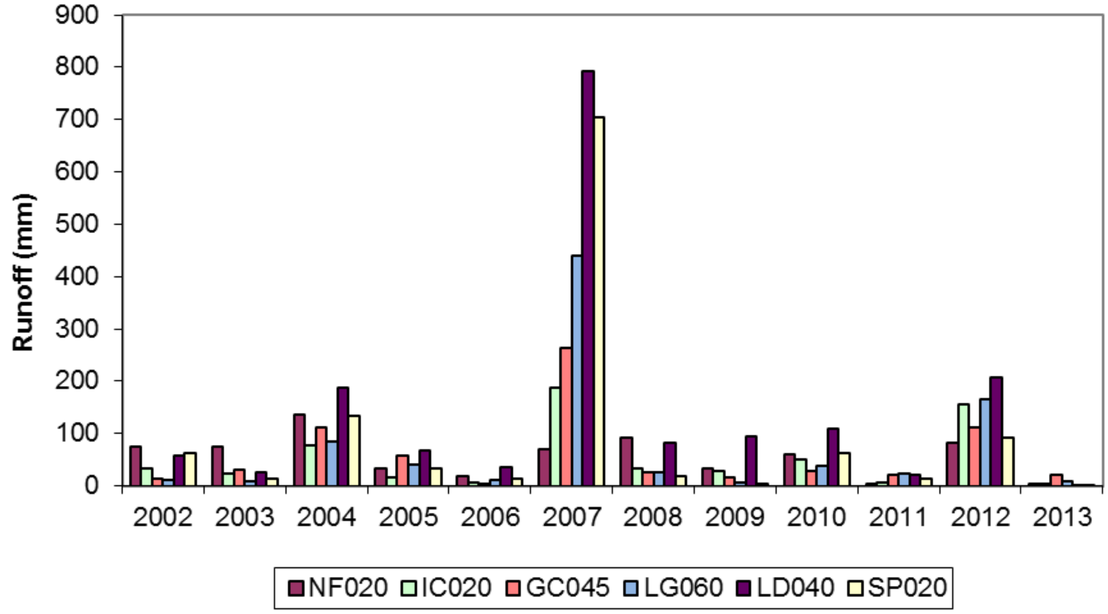

Figure 5 Estimated annual runoff for selected microwatershed sites throughout the upper North Bosque River watershed. Sites are ordered in general from north to south within the watershed.

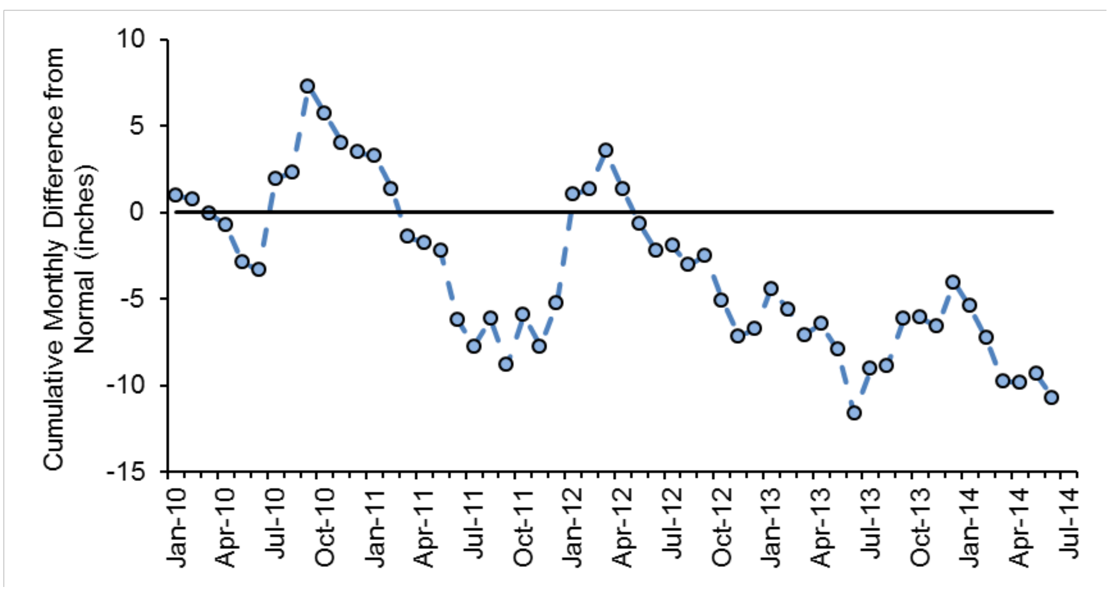

Figure 6 Rainfall deficit represented as cumulative monthly difference in precipitation from normal for Stephenville, Texas. Source: NCDC (2014a), monthly normals based on data from 1981-2010.

These drought conditions can have their own impact on stream water quality, as drought can make soil very dry and powdery, decrease cover provided by vegetation, and allow a build-up of debris on the landscape surface and within stream channels. When runoff does occur, it may flush accumulated debris within the stream channel and more easily move loose topsoil from the land. Significant increasing trends in TSS were noted at several sites including SP020, a least impacted reference site, that may indicate the influence of these drought conditions in these watersheds on water quality (Table 9). Significant increases in TSS accompanied significant increases in TKN and/or total P at sites NF009, SF085, and SP020 indicating an increase in particulate bound nutrients.

While weather has a direct influence on stream water quality, so do changes in land use. In part, changes in land use are occurring in the North Bosque River watershed due to implementation of CNMPs and NMPs, particularly for AFOs and CAFOs. As NMPs are developed, they take into account soil phosphorus concentrations of land management units in developing appropriate manure application rates. It is generally recommended that land areas with high levels of soil phosphorus concentrations be removed from the waste management plan, as little if any manure or effluent can be applied to these fields. Changing to manure application rates based on soil phosphorus concentrations, as recommended as part of NMPs, has been shown to greatly reduce phosphorus in runoff (McFarland and Hauck, 2004). Fields that have been WAFs that no longer have manure applied and are removed from a CAFO permit for waste application become historical WAFs.

To aid in tracking these changes in land use, the land area associated with animal WAFs was updated to reflect current and historical fields (Figure 7 and Table 10). Historical WAFs represent fields that were once permitted that are no longer permitted for waste application or areas associated with nonpermitted AFOs that are no longer in operation. This update to the land area associated with WAFs was conducted by TIAER under an associated Clean Water Act 319(h) project funded through TCEQ, and details of how this update was conducted are provided in McFarland and Adams (2014b). This update involved a review of permit files and a mapping of any new WAFs based on TCEQ records reviewed in 2011 and updated in 2012 and 2013. Changes in land use based on information given in Tables 2 and 10 were then compared to trends in water quality for microwatershed sampling sites.

Of the four watersheds (GB020, GM060, IC020, and NF020) showing significant decreases in phosphorus (PO_4-P and/or total P), the influence of removing some land area from active waste application was unclear. Only two (IC020 and NF020) of these four watersheds indicated greater than 10 percent of the land shifting from active to historical waste applications fields (Table 10). In the watersheds above sites GB020 and GM060, less than two percent of the land area associated with animal waste application was noted as historical indicating only very small shifts compared to the total microwatershed drainage area.

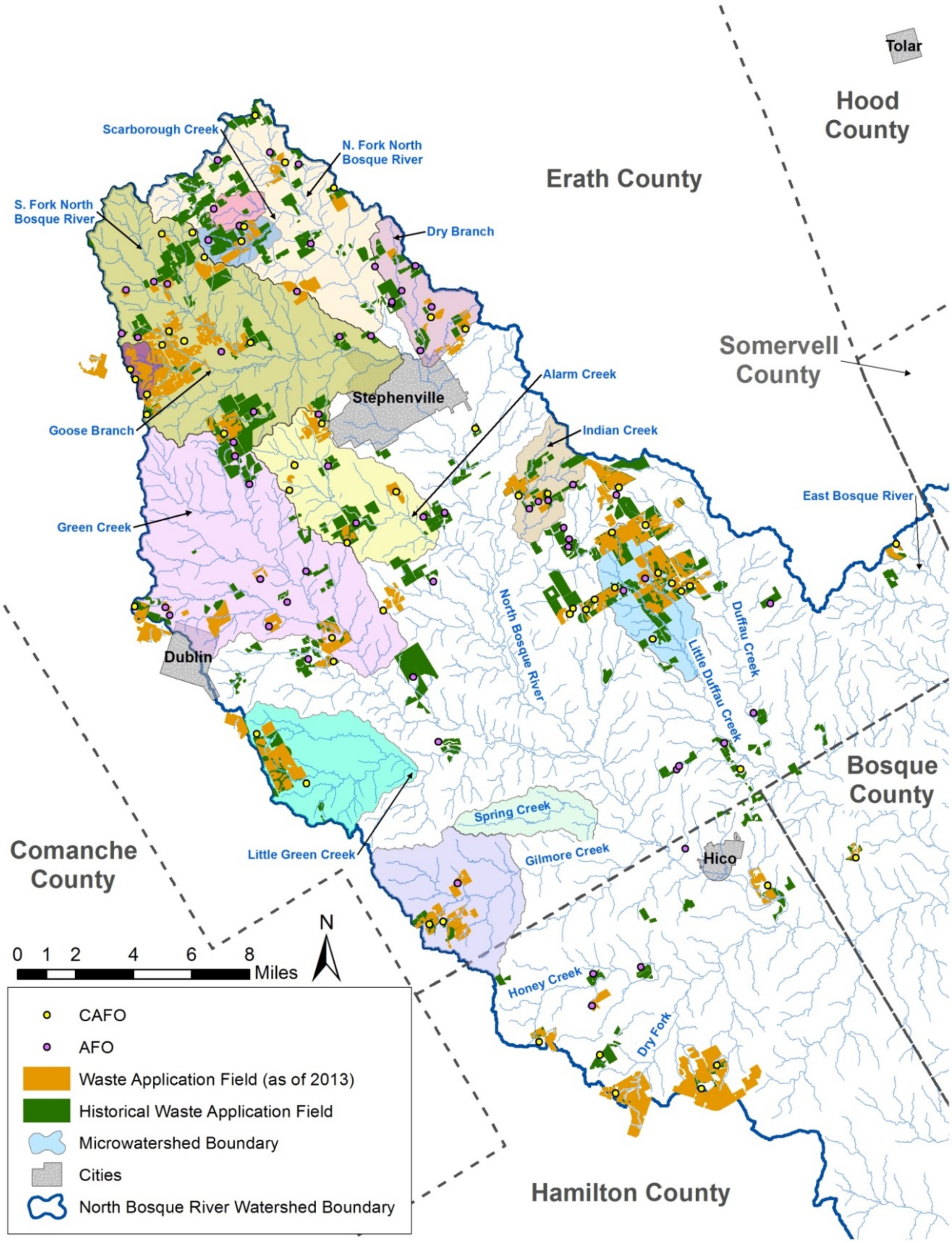

Figure 7 Map of CAFOs, AFOs, and associated WAFs (active and historical) within the North Bosque River watershed. Represents conditions as of fall 2013 for WAFs. Dots denote the location of active CAFOs and AFOs as of 2001 and includes not only dairies, but calf and beef operations as well as sale barns within the watershed.

Table 10 Land use changes for animal waste application fields.

Site	Wood & Range (%)	Pasture (%)	Cropland (%)	Animal Waste App. Fields [a] (%)	Historical Animal Waste Appl. Fields [b] (%)	Urban or Impervious Surfaces (%)	Other (%)	Total Area (Hectares)
AL020	31.7	44.8	7.1	4.5	8.3	2.8	0.8	4,720
DB035	22.8	42.9	10.5	5.5	12.9	3.5	1.9	2,130
GB020	21.4	22.6	8.2	41.4	0.6	4.0	1.7	440
GC045	31.1	49.1	8.4	3.4	4.7	2.4	0.9	11,900
GM060	55.6	33.7	0.8	6.7	1.8	1.1	0.2	4,410
IC020	36.3	35.4	6.5	6.3	13.4	1.6	0.4	1,740
LD040	32.5	25.2	5.5	21.5	14.0	0.3	1.0	2,960
LG060	38.9	38.8	8.2	8.5	3.7	1.0	0.9	4,260
NF009	30.6	49.6	2.6	0.2	13.8	2.8	0.4	520
NF020	19.6	33.7	2.6	14.5	26.9	1.7	1.0	800
NF050	23.1	47.5	7.3	4.1	14.3	2.8	0.8	8,370
SF085	27.8	36.8	11.1	9.7	9.1	4.5	1.1	12,900
SP020	65.0	33.2	1.3	0.0	0.0	0.3	0.2	1,560

a. Animal waste application fields represent estimates from milking operations and non-milking operations.

b. Historical fields are field previously used or permitted animal waste application that are no longer receiving or permitted for animal waste.

As noted in McFarland and Adams (2014b), many of the dairy operations still in business have expanded or identified new fields for manure application as permits have been renewed. While some fields are no longer used for manure or effluent application, there are new land areas being designated for animal waste application. In one microwatershed (GM060), there was actually an increase in the land area associated with WAFs between 2005 and 2013 (see Tables 2 and 10). This increase in WAFs within the Gilmer Creek microwatershed above site GM060 was relatively small making up less than one percent in an area where WAFs are less than seven percent of the total land area. Overall within the watershed, a notable decrease has occurred in the land area being used for WAFs (Table 11), which in part is associated with some of the decreases in stream phosphorus concentrations noted in microwatershed stream sites, such as IC020 and NF020, as well as along the mainstem of the North Bosque River (McFarland and Adams, 2014b).

Other changes in the watershed include a decline in the number of active dairy operations, although this decline does not reflect a commensurate decline in cow numbers. Based on TCEQ inspection records for the North Bosque River watershed, the estimated number of dairy cows was about 45,000 in 2001 and about 32,000 in 2013, while the number of active dairy operations has declined from about 91 in 2001 to about 55 in 2013. Although only about two-thirds of the dairy operations in Erath County are within the North Bosque River watershed, county level statistics provided by the United States Department of Agriculture (USDA) help illustrate this point comparing the number of dairies versus total milk production (Figure 8).

Table 11 Comparison of acres and number of fields categorized as active and historical WAFs in the North Bosque River watershed as 2000, 2005, and 2013. Information on WAFs for 2000 and 2005 from McFarland and Jones (2006) for 2013 from McFarland and Adams (2014b).

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

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

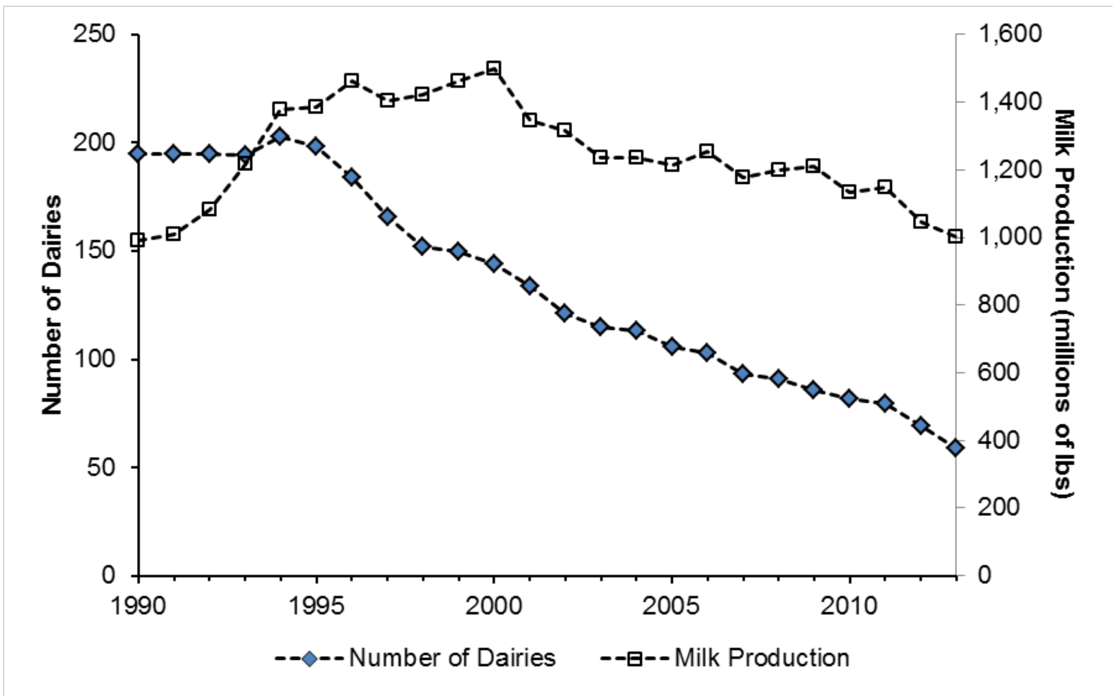

Figure 8 Annual variation in the number of dairy operations and milk production for Erath County, Texas. Source: United States Department of Agriculture Agricultural Marking Service (USDA-AMS) milk marketing production records (e.g., USDA-AMS, 2014).

Another factor affecting phosphorus available for runoff, and, thus, water quality at these microwatershed sites is the manure composting program. As found previously (e.g., Millican and McFarland 2008), decreasing trends in phosphorus were associated with microwatershed sites that had higher rates of participation in the haul-off of manure to composting facilities. While total amounts of manure hauled were larger in other watersheds (Figure 9), three of the four sites showing decreasing phosphorus (GB020, IC020, and NF020) also showed the highest rates of participation in the manure haul-off program, when the amount of manure hauled was normalized on a cow and per unit area basis (Figure 10).

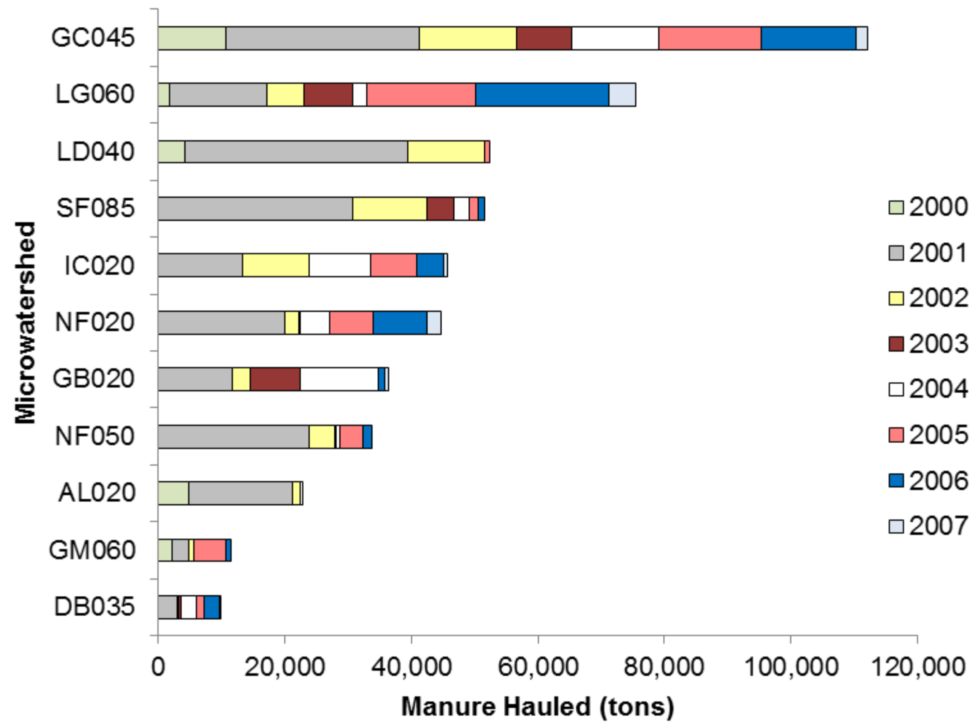

Figure 9 Manure hauled to composting facilities from within microwatershed drainage areas between November 2000 and February 2007. Note: The manure haul-off program ended in February 2007.

The fourth site with decreasing trends in phosphorus was GM060. Less than 10 percent of the land area within the Gilmer Creek microwatershed is associated with WAFs (Table 10) and only a limited amount of manure hauled was hauled from this area (Figures 9 and 10). Within the Gilmer Creek microwatershed, large amounts of the land area are associated with grazing cattle. Reduced stocking rates and improved grazing management practices, such as providing alternative water supplies and exclusionary fencing along creeks, may be responsible for decreasing phosphorus trends in this microwatershed.

In contrast, site LD040, which had a fairly large total amount of manure hauled (Figure 9), showed increasing trends in phosphorus, but also indicated much lower normalized amounts of manure hauled than sites, such as NF020 and GB020, that showed decreasing trends (Figure 10). The land use within the LD040 microwatershed maintains one of the highest percentages of land associated with WAFs at almost 22 percent (Table 10), although the reasons for the increase in stream phosphorus at LD040 observed are uncertain.

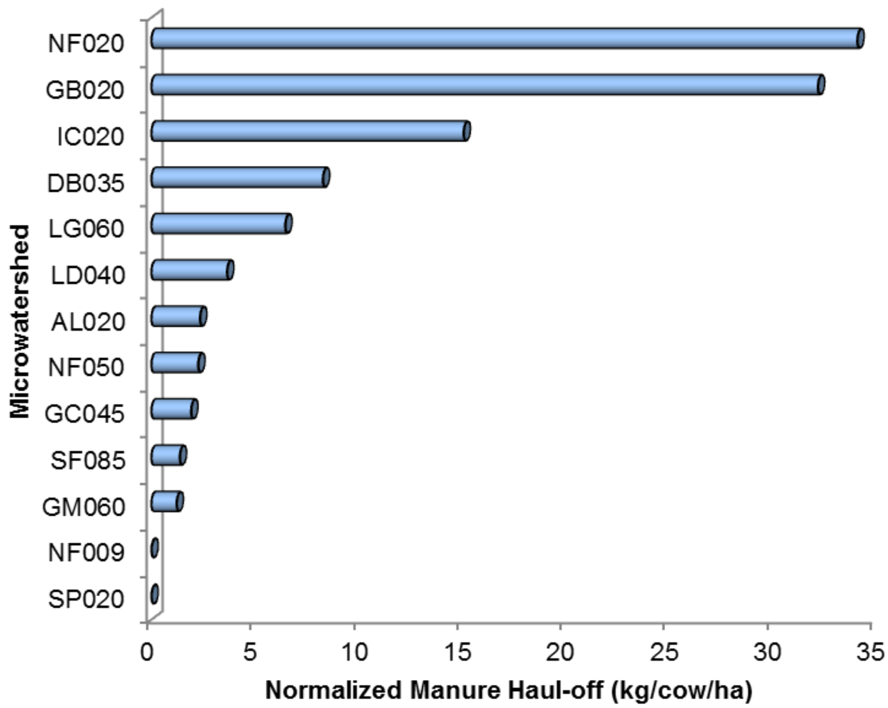

Figure 10 Manure hauled normalized for drainage area and average cow numbers.

While it is not known specifically why increasing trends in phosphorus were noted at site LD040, one possibility apart from WAFs may be land-use changes that have increased the use of commercial fertilizer. A comparison of land-use data from the late 1990s with data from the mid-2000s indicates across the watershed an increase of about 20 percent in land associated with improved pasture and cropland with a commensurate decrease in land associated with wood and rangeland (Millican and McFarland, 2008). While fertilizer sales for the area have decreased notably over time (Figure 11), it is possible that the use of commercial fertilizer may have increased in some microwatersheds.

Another factor to consider in microwatersheds with increasing phosphorus trends is the major form of phosphorus entering the stream, which likely will direct control practices. At both sites NF009 and SF085, increasing trends were noted in PO_4-P and total-P as well as in TSS. This commensurate increase in phosphorus with TSS indicates an increase in particulate movement that might be associated with an increase in dry deposition linked to drought within these microwatersheds. At site LD040, only PO_4-P, representing the soluble portion of total-P, showed an increase suggesting a need to focus control practices on the movement of soluble rather than particulate phosphorus in this microwatershed.

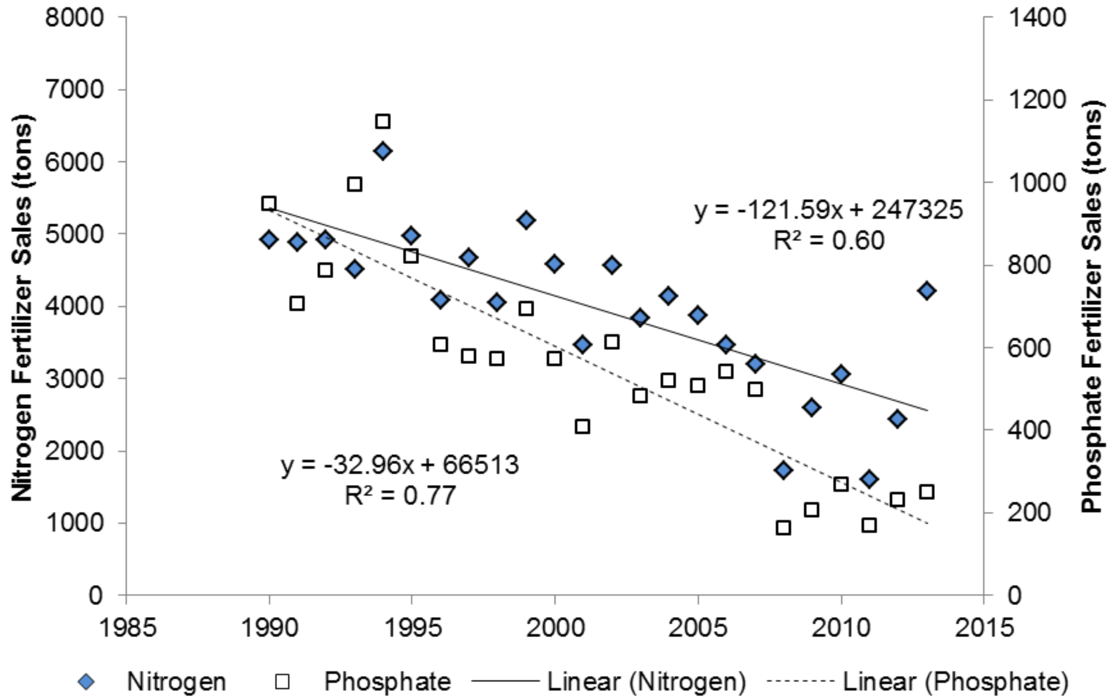

Figure 11 Annual sale of commercial fertilizer for Erath County for 1990-2013. Source: Office of the Texas State Chemist, Annual Fertilizer Report by County (OTSC, 2014).

CHAPTER 5

Conclusions

Significant reductions in stream phosphorus concentrations are occurring at microwatershed sites within the North Bosque River watershed. These reductions were most noticeable in microwatersheds that have had a large percentage of land area associated with WAFs, such as GB020 and NF020, which as of 2005 had over 40 percent. Above site NF020, the land use has shifted with nearly 27 percent of WAFs as of 2013 designated as historical and only about 15 percent as active WAFs. In the GB020 mircowatershed, about 40 percent of the land area is still represented as active WAFs with only a few fields becoming historical. This indicates in the GB020 microwatershed that declines in stream phosphorus are likely due to changes in the management of these WAFs.

Declines in phosphorus were also noted in the Indian Creek and Gilmer Creek watersheds, which have smaller amounts of land associated with WAFs. In the watershed above site IC020, only about 19 percent of the land area has been associated with WAFs and much of that has shifted to historical WAFs with only about 6 percent now considered active WAFs. For the watershed above site GM060, the land area associated with WAFs has been relatively small (less than 7 percent), and it appears likely that changes in grazing and pasture management are influencing the decreases in phosphorus occurring in this microwatershed.

With regard to TMDL I-Plan activities, the implementation of CNMPs appears to be an important component in these phosphorus reductions. The development of CNMPs has facilitated the shift from active to historical WAFs as fields high in soil phosphorus have been removed from active status. Another I-Plan component that continues to have a residual impact is the manure haul-off and composting program. This program ended in 2007, but microwatersheds that had the largest haul-off when normalized by watershed area and cow number continue to show some of the largest improvements in water quality. These reductions in phosphorus at the mircowatershed scale contribute to reductions along the mainstem of the North Bosque River as it nears meeting TMDL water quality goals. As of 2013, four of the five index stations along the mainstem of the North Bosque River used for measuring success of the TMDLs are meeting goals in most years and decreasing trends in orthophosphorus are noted at all but the most upstream station (McFarland and Adams, 2014b and TCEQ, 2013).

Success for the North Bosque River is nearing, but still there are areas where implementation practices might be targeted. Increasing phosphorus concentrations as noted for site LD040 on Little Duffau Creek, highlights an area where further improvements are needed with regard to nutrient management, which may need to address WAFs but also the use of commercial fertilizer on improved pasture. Other microwatersheds, such as above NF009 and SF085, showed significant increases in TSS along with increases in phosphorus, together indicating a potential need to focus on erosion control practices to reduce the movement of particulate phosphorus.

Improvements in the North Bosque watershed are slowly being realized. The lag of years (even decades) between implementation of land practices and improvements in stream water quality is expected (e.g., Meals et al., 2010), but is being overcome. Improvements are also expected to continue as long a good land management practices continue to be implemented. Weather conditions in conjunction with land management practices will continue to play an important role in influencing the success of I-Plan activities. Under drought conditions, it is particularly important to restrict nutrient application rates, because with lower crop yields, over-application is even more likely to lead to nutrients in the creek when rainfall-runoff does occur. Proper nutrient management of animal waste and fertilizer is key to controlling NPS contributions of phosphorus to the stream, thus, curbing excessive algal growth, and allowing the North Bosque River to meet TMDL water quality target goals.

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APPENDIX A

Summary Statistics for Routine Grab Samples

All data analyses represent routine grab samples collected between January 1, 2001 and December 31, 2013. The exact date range of samples evaluated will vary by site based on monitoring history. The LOQ represents the limit of quantification for laboratory parameters as outlined in the project QAPP. Values less than the LOQ were represented as half the LOQ for statistical evaluations.

Table A-1 Routine grab sample summary statistics for site AL020 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Min.	Max.	N	LOQ	# < LOQ
Water Temp. (°C)	16.3	17.2	6.6	2.0	30.9	111	--	--
Specific Conductance (µS/cm)	1040	1020	579	97	2610	111	--	--
Dissolved Oxygen (mg/L)	7.2	6.7	3.1	1.2	13.4	111	--	--
pH (standard units)	7.9	7.9	0.3	7.4	9.0	111	--	--
PO_4-P (mg/L)	0.192	0.126	0.199	0.003	0.887	111	0.005	2
Total P (mg/L)	0.34	0.25	0.34	0.03	2.59	110	0.06	5
NH_3-N (mg/L)	0.102	0.050	0.102	0.050	0.736	111	0.100	58
NO_2-N+NO_3-N (mg/L)	0.706	0.187	1.044	0.025	4.880	111	0.050	33
TKN (mg/L)	1.15	1.01	0.76	0.10	4.55	111	0.20	10
TSS (mg/L)	25	8	53	2	422	111	4	27
Fecal Coliform (colonies/100 mL)	3100	350	13000	12	69000	29	1	0
E. coli (colonies/100 mL)	2600	230	9000	3	54000	97	1	0

Table A-2 Routine grab sample summary statistics for site DB035 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Min.	Max.	N	LOQ	# < LOQ
Water Temp. (°C)	15.2	15.8	6.2	2.8	26.5	68	--	--
Specific Conductance (µS/cm)	1060	994	583	231	2350	68	--	--
Dissolved Oxygen (mg/L)	9.6	9.3	3.5	3.8	20.9	68	--	--
pH (standard units)	8.0	8.0	0.2	7.7	8.8	68	--	--
PO_4-P (mg/L)	0.476	0.426	0.314	0.008	1.50	68	0.005	0
Total P (mg/L)	0.66	0.58	0.39	0.03	1.70	68	0.06	1
NH_3-N (mg/L)	0.126	0.053	0.159	0.050	0.733	68	0.100	33
NO_2-N+NO_3-N (mg/L)	1.42	0.979	1.59	0.025	6.03	68	0.050	7
TKN (mg/L)	1.69	1.53	0.77	0.25	4.22	68	0.20	0
TSS (mg/L)	18	11	25	2	144	68	4	10
Fecal Coliform (colonies/100 mL)	1300	270	3200	52	14000	22	1	0
E. coli (colonies/100 mL)	5200	350	22000	2	140000	64	1	0

Table A-3 Routine grab sample summary statistics for site GB020 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Min.	Max.	N	LOQ	# < LOQ
Water Temp. (°C)	12.6	10.7	7.5	4.1	23.6	9	--	--
Specific Conductance (µS/cm)	931	437	1080	178	3270	9	--	--
Dissolved Oxygen (mg/L)	8.5	8.8	2.6	5.2	11.6	9	--	--
pH (standard units)	8.1	8.1	0.2	7.8	8.5	9	--	--
PO_4-P (mg/L)	4.57	4.09	2.42	0.691	7.60	8	0.005	0
Total P (mg/L)	9.63	5.65	8.58	3.36	28.2	9	0.06	0
NH_3-N (mg/L)	0.494	0.304	0.519	0.079	1.59	7	0.100	0
NO_2-N+NO_3-N (mg/L)	3.19	1.45	3.61	0.240	9.87	9	0.050	0
TKN (mg/L)	33.3	6.09	61.2	3.04	187	9	0.20	0
TSS (mg/L)	360	122	639	2	1980	9	4	1
Fecal Coliform (colonies/100 mL)	260000	260000	360000	9700	510000	2	1	0
E. coli (colonies/100 mL)	170000	61000	200000	7300	500000	8	1	0

Table A-4 Routine grab sample summary statistics for site GC045 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Min.	Max.	N	LOQ	# < LOQ
Water Temp. (°C)	17.5	19.0	6.8	3.6	28.0	121	--	--
Specific Conductance (µS/cm)	706	671	240	306	1440	121	--	--
Dissolved Oxygen (mg/L)	8.0	7.7	2.3	2.2	13.5	121	--	--
pH (standard units)	7.9	7.9	0.2	7.1	8.4	121	--	--
PO_4-P (mg/L)	0.061	0.011	0.120	0.003	0.889	121	0.005	18
Total P (mg/L)	0.15	0.09	0.16	0.03	1.11	121	0.06	32
NH_3-N (mg/L)	0.073	0.050	0.065	0.050	0.586	121	0.100	85
NO_2-N+NO_3-N (mg/L)	3.63	1.39	5.10	0.025	22.2	121	0.050	30
TKN (mg/L)	0.83	0.69	0.59	0.10	2.31	121	0.20	17
TSS (mg/L)	15	6	21	2	112	120	4	51
Fecal Coliform (colonies/100 mL)	500	160	1000	2	4500	21	1	0
E. coli (colonies/100 mL)	2700	120	23000	1	240000	108	1	2

Table A-5 Routine grab sample summary statistics for site GM060 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Min.	Max.	N	LOQ	# < LOQ
Water Temp. (°C)	17.2	17.4	7.7	2.5	37.4	129	--	--
Specific Conductance (µS/cm)	852	789	317	128	1720	129	--	--
Dissolved Oxygen (mg/L)	9.9	9.9	2.0	5.2	15.1	129	--	--
pH (standard units)	8.0	8.1	0.2	7.5	8.8	129	--	--
PO_4-P (mg/L)	0.079	0.019	0.148	0.003	1.03	129	0.005	9
Total P (mg/L)	0.16	0.08	0.20	0.03	1.46	129	0.06	25
NH_3-N (mg/L)	0.068	0.050	0.089	0.050	0.917	129	0.100	108
NO_2-N+NO_3-N (mg/L)	0.114	0.025	0.268	0.025	2.16	129	0.050	78
TKN (mg/L)	0.51	0.42	0.44	0.10	2.78	129	0.20	30
TSS (mg/L)	12	2	49	2	544	129	4	65
Fecal Coliform (colonies/100 mL)	790	35	4200	2	26000	38	1	0
E. coli (colonies/100 mL)	1200	25	5100	1	41000	110	1	2

Table A-6 Routine grab sample summary statistics for site IC020 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Min.	Max.	N	LOQ	# < LOQ
Water Temp. (°C)	17.7	18.3	7.1	4	31.3	78	--	--
Specific Conductance (µS/cm)	1190	1160	561	157	2800	78	--	--
Dissolved Oxygen (mg/L)	12.2	11.9	3.1	5.8	20.8	78	--	--
pH (standard units)	8.2	8.3	0.3	7.5	8.9	78	--	--
PO_4-P (mg/L)	0.282	0.134	0.441	0.0025	3.01	78	0.005	3
Total P (mg/L)	0.49	0.27	0.68	0.03	4.16	78	0.06	7
NH_3-N (mg/L)	0.207	0.050	0.520	0.050	3.68	77	0.100	49
NO_2-N+NO_3-N (mg/L)	2.33	1.52	3.41	0.025	20.1	78	0.050	20
TKN (mg/L)	1.87	1.39	2.05	0.10	15.3	78	0.20	4
TSS (mg/L)	18	8	36	2	240	78	4	21
Fecal Coliform (colonies/100 mL)	13000	780	51000	1	220000	18	1	1
E. coli (colonies/100 mL)	3400	270	16000	1	120000	63	1	2

Table A-7 Routine grab sample summary statistics for site LD040 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Min.	Max.	N	LOQ	# < LOQ
Water Temp. (°C)	15.6	16.2	6.4	3.5	26.8	69	--	--
Specific Conductance (µS/cm)	1230	1270	506	127	2390	69	--	--
Dissolved Oxygen (mg/L)	8.7	8.6	3.0	1.3	16.6	69	--	--
pH (standard units)	7.9	7.9	0.2	7.5	8.3	69	--	--
PO_4-P (mg/L)	0.525	0.378	0.448	0.008	2.47	69	0.005	0
Total P (mg/L)	0.81	0.51	0.93	0.03	5.40	69	0.06	1
NH_3-N (mg/L)	0.215	0.062	0.446	0.050	2.52	67	0.100	30
NO_2-N+NO_3-N (mg/L)	3.27	1.93	3.93	0.025	14.4	69	0.050	7
TKN (mg/L)	2.79	1.49	5.84	0.10	36.6	69	0.20	2
TSS (mg/L)	25	9	39	2	202	69	4	15
Fecal Coliform (colonies/100 mL)	6200	1400	9700	46	24000	9	1	0
E. coli (colonies/100 mL)	12000	490	31000	8	170000	63	1	0

Table A-8 Routine grab sample summary statistics for site LG060 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Min.	Max.	N	LOQ	# < LOQ
Water Temp. (°C)	17.1	17.8	6.9	2.8	29.0	101	--	--
Specific Conductance (µS/cm)	658	651	231	171	1100	101	--	--
Dissolved Oxygen (mg/L)	9.5	9.1	2.5	4.7	15.2	101	--	--
pH (standard units)	8.1	8.1	0.2	7.7	8.6	101	--	--
PO_4-P (mg/L)	0.080	0.029	0.157	0.003	1.39	101	0.005	14
Total P (mg/L)	0.18	0.12	0.21	0.03	1.73	101	0.06	17
NH_3-N (mg/L)	0.093	0.050	0.112	0.050	0.895	101	0.100	57
NO_2-N+NO_3-N (mg/L)	0.498	0.204	0.685	0.025	2.51	101	0.050	25
TKN (mg/L)	1.10	0.78	1.07	0.10	8.85	101	0.20	10
TSS (mg/L)	20	8	28	2	171	101	4	26
Fecal Coliform (colonies/100 mL)	4400	760	10000	70	39500	21	1	0
E. coli (colonies/100 mL)	6800	330	26000	1	199000	89	1	1

Table A-9 Routine grab sample summary statistics for site NF009 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Min.	Max.	N	LOQ	# < LOQ
Water Temp. (ºC)	14.5	15.2	6.5	2.6	26.8	103	--	--
Specific Conductance (µS/cm)	2070	2000	903	270	4290	103	--	--
Dissolved Oxygen (mg/L)	7.3	7.3	3.4	1.4	16.9	103	--	--
pH (standard units)	7.9	7.8	0.2	7.4	8.7	103	--	--
PO_4-P (mg/L)	0.177	0.100	0.176	0.003	0.750	103	0.005	1
Total P (mg/L)	0.34	0.26	0.27	0.03	1.63	103	0.06	2
NH_3-N (mg/L)	0.148	0.050	0.230	0.050	1.42	102	0.100	63
NO_2-N+NO_3-N (mg/L)	0.346	0.025	0.753	0.025	4.01	103	0.050	55
TKN (mg/L)	1.46	1.15	1.71	0.10	15.9	103	0.20	6
TSS (mg/L)	22	10	34	2	274	103	4	15
Fecal Coliform (colonies/100 mL)	1300	210	2900	22	12000	21	1	0
E. coli (colonies/100 mL)	2800	630	10000	6	92000	94	1	0

Table A-10 Routine grab sample summary statistics for site NF020 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Min.	Max.	N	LOQ	# < LOQ
Water Temp. (ºC)	13.5	14.0	5.3	3.4	25.2	38	--	--
Specific Conductance (µS/cm)	2760	2560	1550	260	5400	38	--	--
Dissolved Oxygen (mg/L)	8.7	8.8	3.5	3.1	18.4	38	--	--
pH (standard units)	8.0	8.0	0.2	7.6	8.5	38	--	--
PO_4-P (mg/L)	0.984	0.831	0.808	0.016	4.08	37	0.005	0
Total P (mg/L)	1.35	1.07	1.04	0.11	4.57	37	0.06	0
NH_3-N (mg/L)	0.393	0.112	0.828	0.050	4.92	38	0.100	12
NO_2-N+NO_3-N (mg/L)	1.36	0.520	1.97	0.025	7.63	38	0.050	9
TKN (mg/L)	3.47	2.59	2.76	1.28	15.5	38	0.20	0
TSS (mg/L)	29	15	38	2	192	38	4	2
Fecal Coliform (colonies/100 mL)	77000	13000	98000	170	190000	5	1	0
E. coli (colonies/100 mL)	11000	650	33000	23	140000	33	1	0

Table A-11 Routine grab sample summary statistics for site NF050 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Min.	Max.	N	LOQ	# < LOQ
Water Temp. (ºC)	16.0	16.8	6.8	1.9	26.9	75	--	--
Specific Conductance (µS/cm)	829	609	642	177	3560	75	--	--
Dissolved Oxygen (mg/L)	9.0	8.3	3.8	2.0	24.8	75	--	--
pH (standard units)	8.2	8.2	0.3	7.6	9.1	75	--	--
PO_4-P (mg/L)	0.335	0.275	0.232	0.014	1.20	75	0.005	0
Total P (mg/L)	0.52	0.46	0.33	0.03	1.76	75	0.06	1
NH_3-N (mg/L)	0.121	0.050	0.164	0.050	1.05	75	0.100	43
NO_2-N+NO_3-N (mg/L)	0.446	0.259	0.632	0.025	4.09	75	0.050	10
TKN (mg/L)	1.87	1.78	0.74	0.48	4.75	75	0.20	0
TSS (mg/L)	28	15	71	2	610	75	4	6
Fecal Coliform (colonies/100 mL)	4400	1100	6300	1	17000	14	1	1
E. coli (colonies/100 mL)	7500	870	30000	1	240000	73	1	1

Table A-12 Routine grab sample summary statistics for site SF085 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Min.	Max.	N	LOQ	# < LOQ
Water Temp. (ºC)	16.1	16.7	7.1	1.2	28.7	181	--	--
Specific Conductance (µS/cm)	717	708	318	152	1630	181	--	--
Dissolved Oxygen (mg/L)	8.7	8.4	3.1	2.3	16.6	181	--	--
pH (standard units)	8.1	8.1	0.2	7.6	9.0	181	--	--
PO_4-P (mg/L)	0.211	0.185	0.175	0.003	1.22	181	0.005	1
Total P (mg/L)	0.32	0.27	0.25	0.03	1.63	181	0.06	6
NH_3-N (mg/L)	0.071	0.050	0.069	0.050	0.554	181	0.100	133
NO_2-N+NO_3-N (mg/L)	0.349	0.215	0.396	0.025	2.36	181	0.050	35
TKN (mg/L)	0.92	0.76	0.69	0.10	3.87	181	0.20	6
TSS (mg/L)	12	4	21	2	160	181	4	82
Fecal Coliform (colonies/100 mL)	570	160	1400	5	7400	45	1	0
E. coli (colonies/100 mL)	3700	210	22000	1	240000	153	1	1

Table A-13 Routine grab sample summary statistics for site SP020 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Min.	Max.	N	LOQ	# < LOQ
Water Temp. (ºC)	16.7	17.3	6.0	4.8	30.1	135	--	--
Specific Conductance (µS/cm)	498	512	66	179	597	135	--	--
Dissolved Oxygen (mg/L)	9.1	8.8	1.5	4.9	12.5	135	--	--
pH (standard units)	7.9	7.9	0.2	7.5	8.7	135	--	--
PO_4-P (mg/L)	0.005	0.003	0.007	0.003	0.048	135	0.005	94
Total P (mg/L)	0.06	0.05	0.04	0.03	0.28	135	0.06	47
NH_3-N (mg/L)	0.051	0.050	0.005	0.050	0.096	135	0.100	130
NO_2-N+NO_3-N (mg/L)	0.088	0.025	0.191	0.025	1.18	135	0.050	90
TKN (mg/L)	0.25	0.18	0.20	0.10	1.17	135	0.20	57
TSS (mg/L)	6	2	19	2	206	135	4	102
Fecal Coliform (colonies/100 mL)	280	110	850	19	5200	37	1	0
E. coli (colonies/100 mL)	450	62	1900	1	19000	111	1	1

APPENDIX B

Summary Statistics for Storm Events

All data analyses represent storms evaluated between January 1, 2001 and December 31, 2013. The exact date range of storm evaluated will vary by site based on monitoring history.

Table B-1 Storm event summary statistics for site AL020 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.308	0.306	0.196	0.003	0.915	95
Total P (mg/L)	0.66	0.65	0.41	0.04	1.74	95
NH_3-N (mg/L)	0.120	0.068	0.126	0.050	1.03	95
NO_2-N+NO_3-N (mg/L)	0.889	0.710	0.861	0.028	5.40	95
TKN (mg/L)	2.13	1.93	1.19	0.10	6.14	95
TSS (mg/L)	190	87	247	2	1130	95

Table B-2 Storm event summary statistics for site DB035 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.570	0.539	0.406	0.061	4.21	117
Total P (mg/L)	0.95	0.89	0.59	0.25	5.74	117
NH_3-N (mg/L)	0.183	0.085	0.274	0.050	2.16	117
NO_2-N+NO_3-N (mg/L)	0.877	0.654	0.864	0.028	7.45	117
TKN (mg/L)	2.24	2.01	1.06	0.82	7.89	117
TSS (mg/L)	134	66	178	7	1180	117

Table B-3 Storm event summary statistics for site GB020 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	2.58	2.23	1.40	0.134	7.14	73
Total P (mg/L)	3.80	3.48	1.67	0.40	9.24	73
NH_3-N (mg/L)	0.743	0.406	1.03	0.050	6.86	72
NO_2-N+NO_3-N (mg/L)	2.74	2.30	2.62	0.262	19.3	73
TKN (mg/L)	6.38	5.29	3.31	0.98	18.1	73
TSS (mg/L)	565	339	784	3	5600	73

Table B-4 Storm event summary statistics for site GC045 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.144	0.116	0.122	0.002	0.496	86
Total P (mg/L)	0.41	0.40	0.28	0.04	1.37	86
NH_3-N (mg/L)	0.094	0.053	0.097	0.010	0.475	86
NO_2-N+NO_3-N (mg/L)	2.90	1.26	4.21	0.028	19.0	86
TKN (mg/L)	1.82	1.70	1.05	0.10	5.19	86
TSS (mg/L)	239	73	598	2	5200	86

Table B-5 Storm event summary statistics for site GM060 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.271	0.216	0.247	0.002	0.857	92
Total P (mg/L)	0.48	0.40	0.37	0.04	1.50	92
NH_3-N (mg/L)	0.093	0.050	0.148	0.050	1.35	92
NO_2-N+NO_3-N (mg/L)	0.305	0.249	0.295	0.028	1.55	92
TKN (mg/L)	1.41	1.28	0.98	0.10	6.35	92
TSS (mg/L)	179	62	401	4	3000	92

Table B-6 Storm event summary statistics for site IC020 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.559	0.535	0.399	0.021	1.91	107
Total P (mg/L)	1.08	0.99	0.61	0.11	2.75	107
NH_3-N (mg/L)	0.239	0.100	0.448	0.050	4.14	107
NO_2-N+NO_3-N (mg/L)	1.27	1.05	1.03	0.028	4.54	107
TKN (mg/L)	3.17	2.81	1.71	0.34	11.5	107
TSS (mg/L)	318	186	351	23	1750	107

Table B-7 Storm event summary statistics for site LD040 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.583	0.593	0.268	0.032	1.25	82
Total P (mg/L)	1.19	1.24	0.48	0.26	2.21	83
NH_3-N (mg/L)	0.392	0.166	0.689	0.016	3.93	82
NO_2-N+NO_3-N (mg/L)	1.753	1.179	2.098	0.028	13.7	83
TKN (mg/L)	3.87	3.48	1.87	0.72	9.81	83
TSS (mg/L)	357	246	376	4	2150	83

Table B-8 Storm event summary statistics for site LG060 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.171	0.129	0.157	0.003	0.737	66
Total P (mg/L)	0.60	0.39	0.64	0.10	3.28	66
NH_3-N (mg/L)	0.136	0.069	0.149	0.010	0.762	66
NO_2-N+NO_3-N (mg/L)	0.503	0.366	0.437	0.028	2.82	66
TKN (mg/L)	2.62	1.82	2.43	0.10	13.2	66
TSS (mg/L)	254	98	403	2	2140	66

Table B-9 Storm event summary statistics for site NF009 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.342	0.329	0.192	0.002	1.24	101
Total P (mg/L)	0.91	0.65	1.25	0.16	10.1	101
NH_3-N (mg/L)	0.275	0.128	0.498	0.050	3.96	101
NO_2-N+NO_3-N (mg/L)	0.784	0.506	1.06	0.028	6.72	101
TKN (mg/L)	3.02	2.29	3.10	0.36	24.1	101
TSS (mg/L)	492	137	1633	13	12300	101

Table B-10 Storm event summary statistics for site NF020 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.884	0.730	0.643	0.028	3.96	107
Total P (mg/L)	1.90	1.57	1.44	0.45	8.40	107
NH_3-N (mg/L)	0.320	0.190	0.396	0.050	2.02	106
NO_2-N+NO_3-N (mg/L)	1.13	0.781	0.918	0.025	6.82	107
TKN (mg/L)	5.07	3.81	3.92	1.39	25.95	107
TSS (mg/L)	641	317	1506	11	14900	107

Table B-11 Storm event summary statistics for site NF050 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.453	0.422	0.190	0.123	1.30	105
Total P (mg/L)	0.89	0.81	0.41	0.18	2.33	105
NH_3-N (mg/L)	0.155	0.108	0.134	0.050	0.746	105
NO_2-N+NO_3-N (mg/L)	0.529	0.443	0.380	0.051	2.13	105
TKN (mg/L)	2.56	2.33	1.34	0.66	8.24	105
TSS (mg/L)	280	106	446	4	2740	105

Table B-12 Storm event summary statistics for site SF085 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.248	0.230	0.122	0.016	0.692	210
Total P (mg/L)	0.508	0.420	0.339	0.052	2.903	210
NH_3-N (mg/L)	0.110	0.050	0.165	0.050	1.86	209
NO_2-N+NO_3-N (mg/L)	0.394	0.329	0.287	0.028	1.86	210
TKN (mg/L)	1.53	1.29	1.12	0.10	9.51	210
TSS (mg/L)	153	50	263	4	1620	210

Table B-13 Storm event summary statistics for site SP020 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.026	0.008	0.051	0.003	0.449	107
Total P (mg/L)	0.18	0.12	0.21	0.04	1.52	107
NH_3-N (mg/L)	0.056	0.050	0.022	0.050	0.203	107
NO_2-N+NO_3-N (mg/L)	0.119	0.049	0.135	0.028	0.673	107
TKN (mg/L)	0.91	0.75	0.97	0.10	7.89	107
TSS (mg/L)	172	38	390	4	3270	107

APPENDIX C

Estimated Average Daily Flow by Site

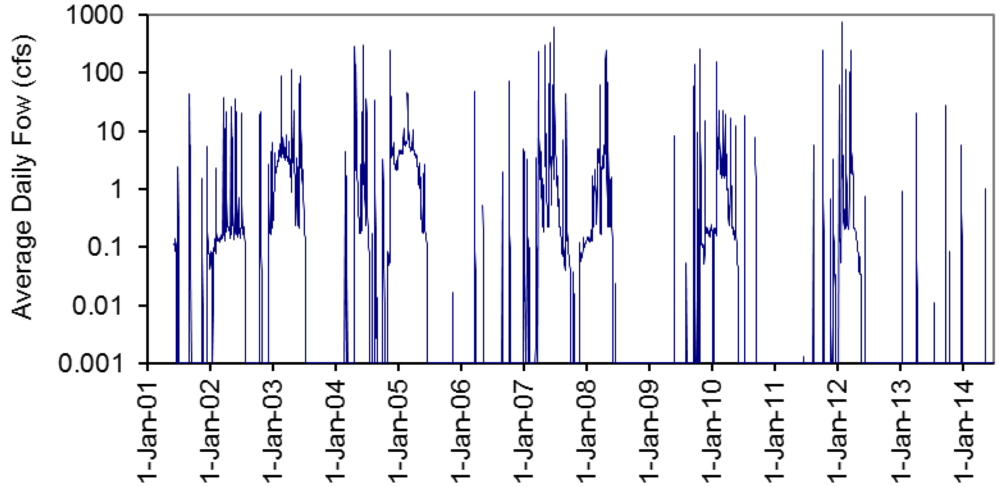

Figure C-1 Average daily flow at AL020 for July 1, 2001 through June 30, 2014. Missing daily estimates exist for July 26-29, 2004; May 6-7, 2006; April 30-May 1, 2007; and September 7-9, 2010.

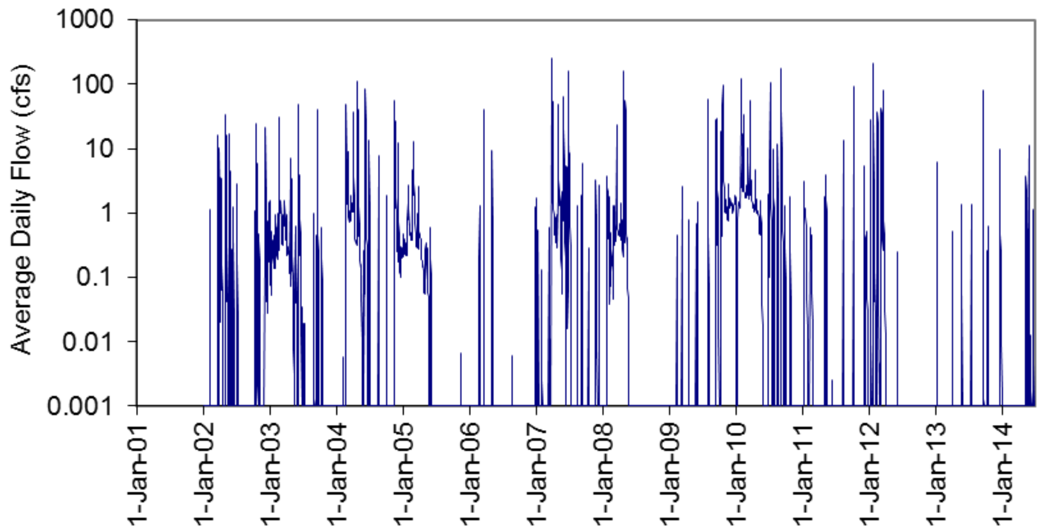

Figure C-2 Average daily flow at DB035 for January 4, 2002 through June 30, 2014. Missing daily estimates exist for January 30 – February 2, 2010 and January 6-8, 2013.

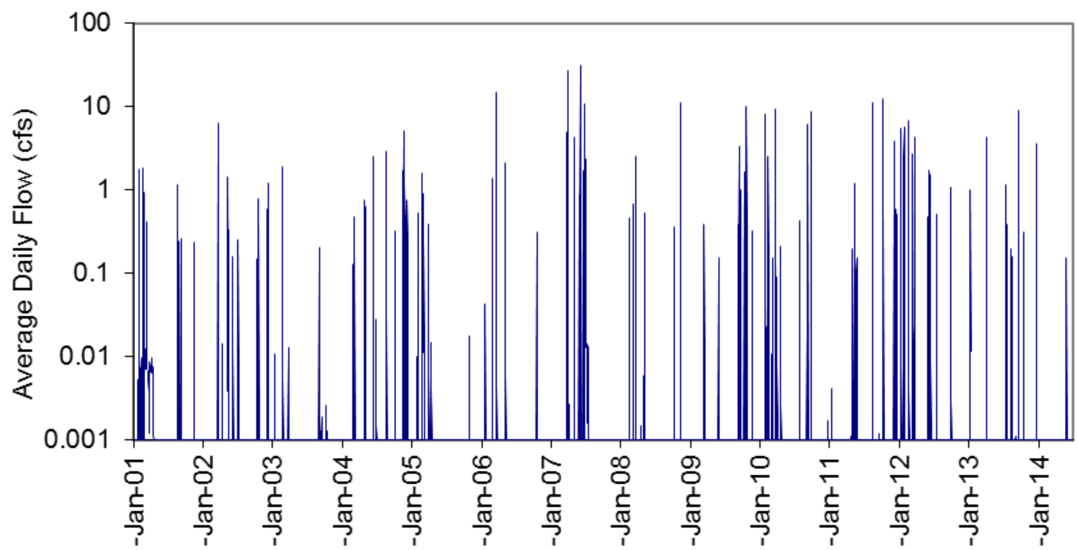

Figure C-3 Average daily flow at GB020 for January 1, 2001 through June 30, 2014. Missing daily estimates exist for March 11-18, 2001; March 30 – April 8, 2002; April 26 – May 6, 2002; April 18-28, 2008; January 23-25, 2012; January 10-15, 2013; and September 21-23, 2013.

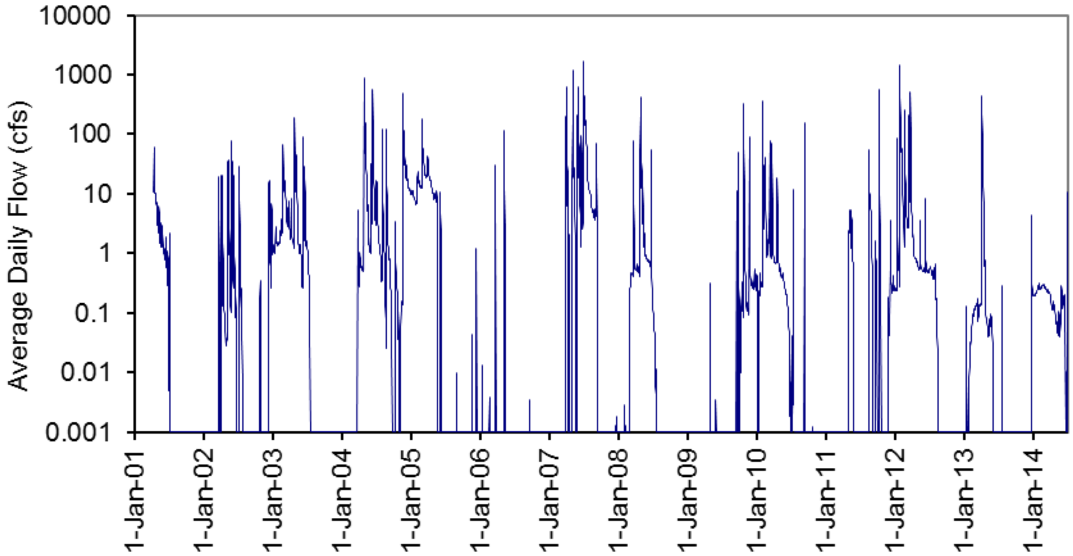

Figure C-4 Average daily flow at GC045 for April 9, 2001 through June 30, 2014.

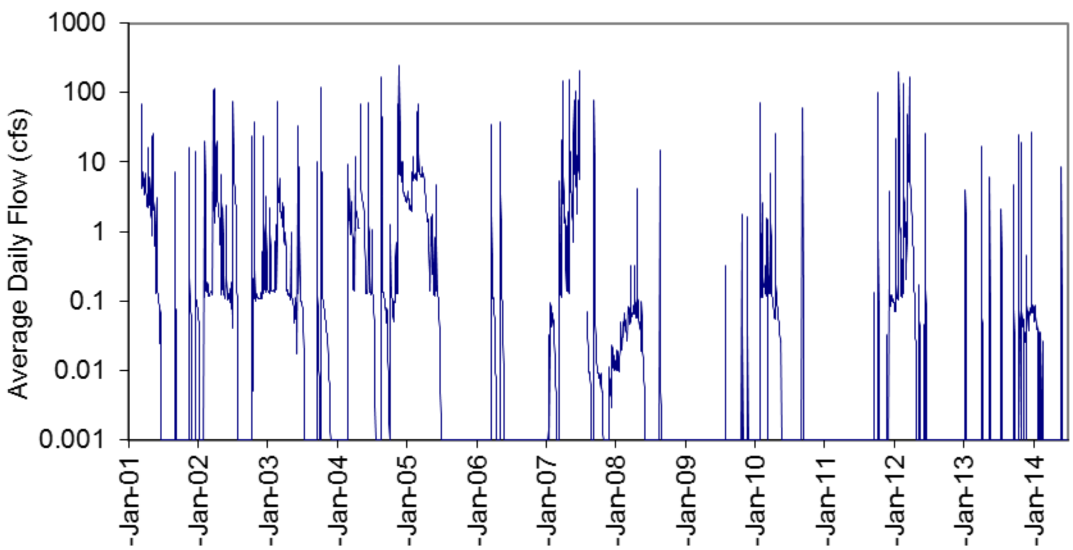

Figure C-5 Average daily flow at GM060 for March 7, 2001 through June 30, 2014. Missing daily estimates exist for April 24-30, 2004; June 27 – August 2, 2007; February 11 – 19, 2010; March 6 – 10, 2010; and September 2 – 7, 2010.

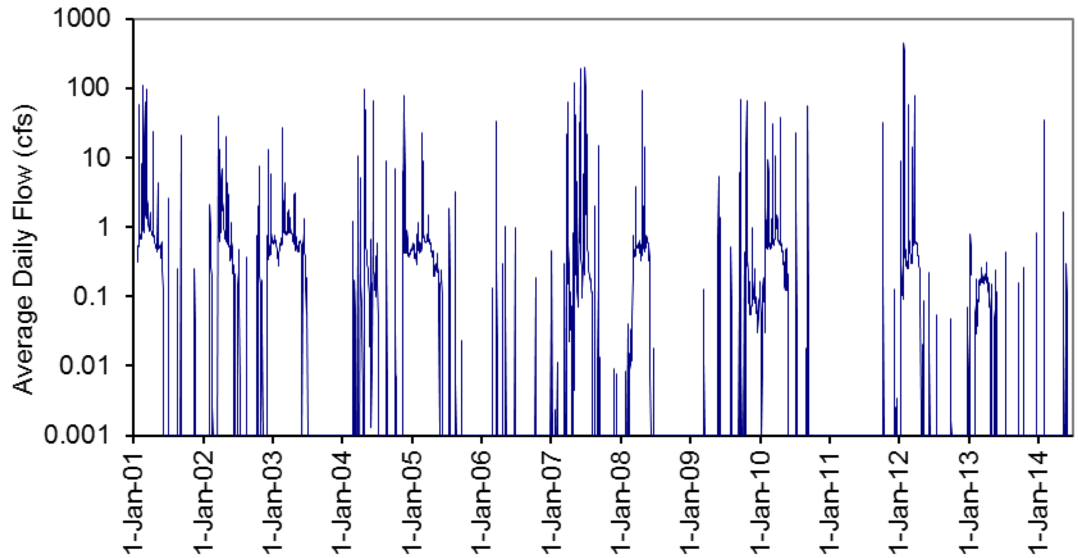

Figure C-6 Average daily flow at IC020 for January 24, 2001 through June 30, 2014. Missing daily estimates exist for November 14-15, 2004 and January 11 – 26, 2013.

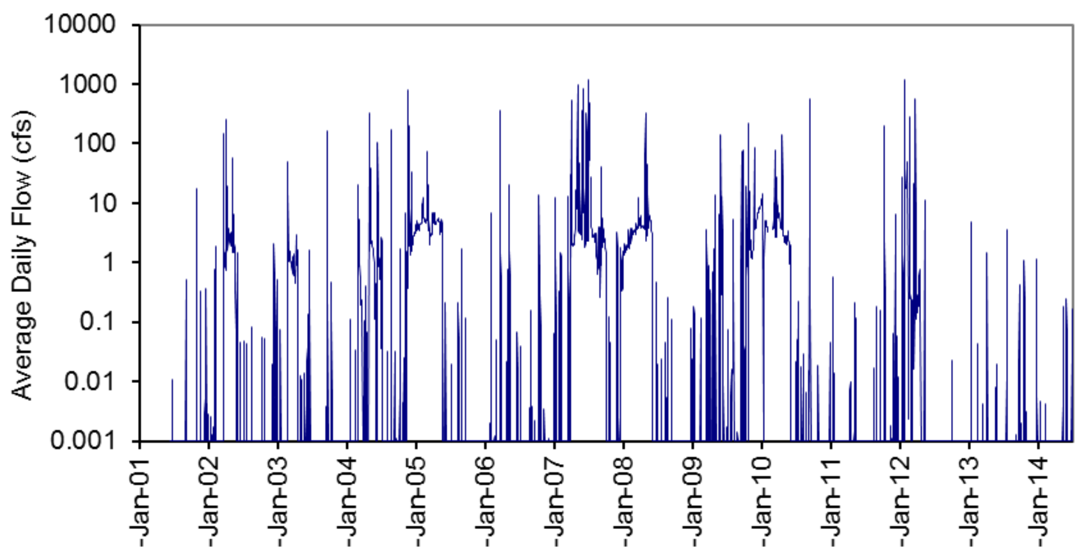

Figure C-7 Average daily flow at LD040 for June 6, 2001 through June 30, 2014. Missing daily estimates exist for July 6-9, 2007; January 27 – February 26, 2010; and January 27 – February 7, 2012.

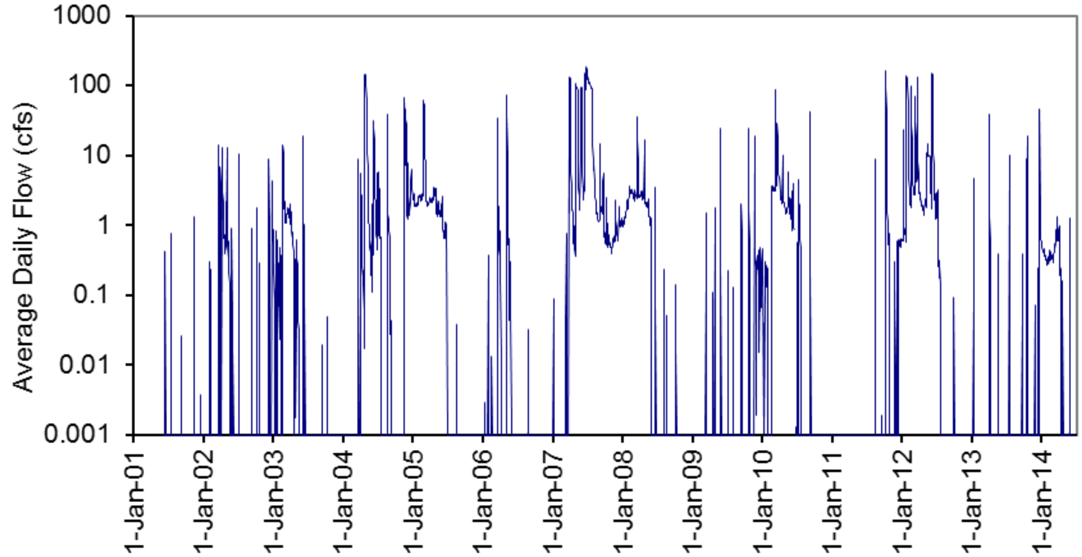

Figure C-8 Average daily flow at LG060 for June 6, 2001 through June 30, 2014. Missing daily estimates exist for April 24-29, 2004 and June 17 – 25, 2010.

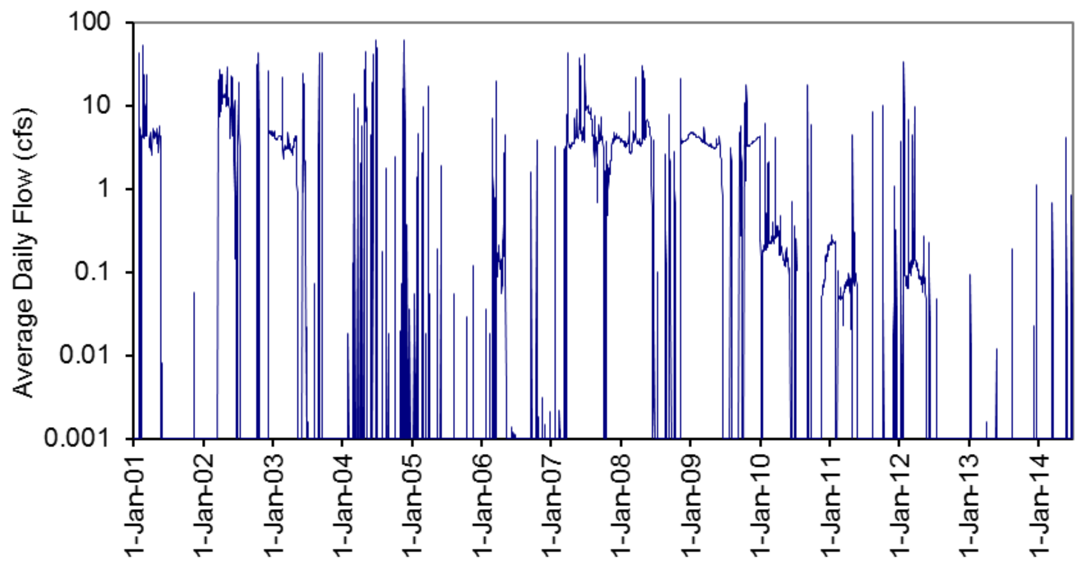

Figure C-9 Average daily flow at NF009 for January 1, 2001 through June 30, 2014. Missing daily estimates exist for March 13-22, 2001; August 31 – September 1, 2003; June 9-15, 2004; and October 4-5, 2004.

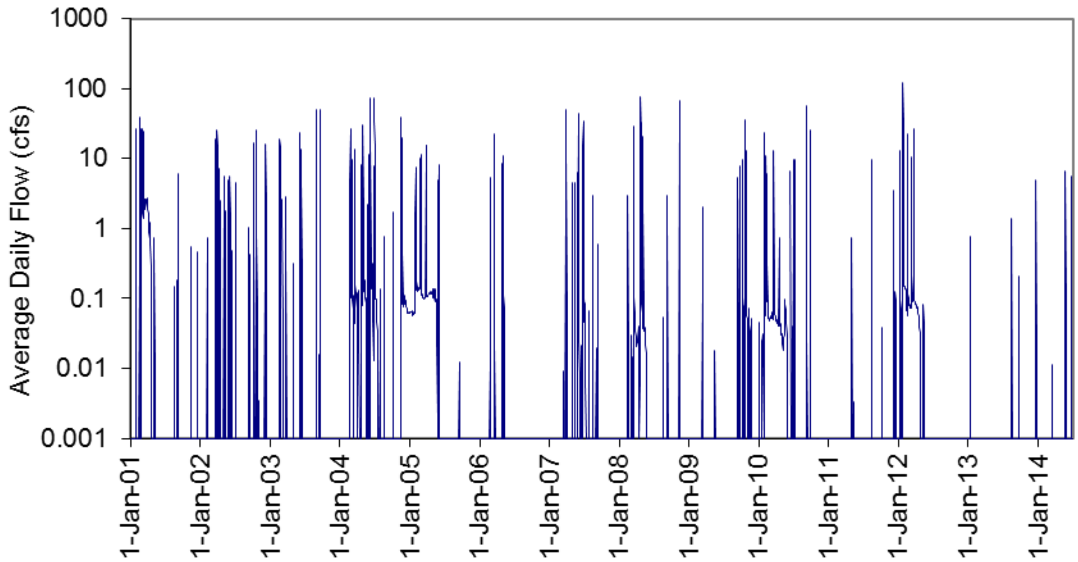

Figure C-10 Average daily flow at NF020 for January 1, 2001 through June 30, 2014. Missing daily estimates exist for June 25-29, 2004 and June 13 – 15, 2010.

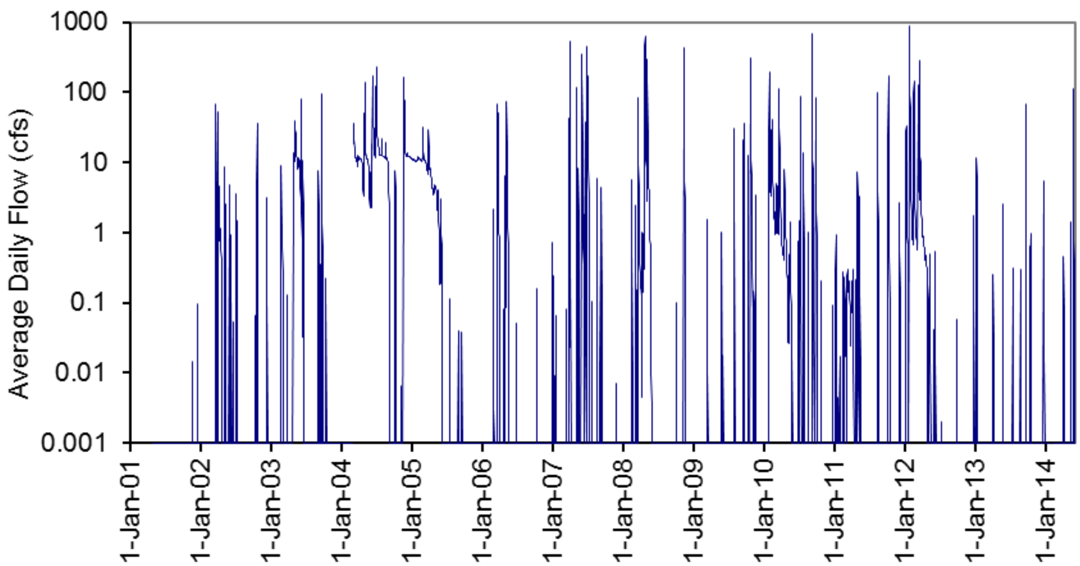

Figure C-11 Average daily flow at NF050 for April 26, 2001 through June 30, 2014. Missing daily estimates exist for February 23 – March 2, 2004 and March 26-27, 2005.

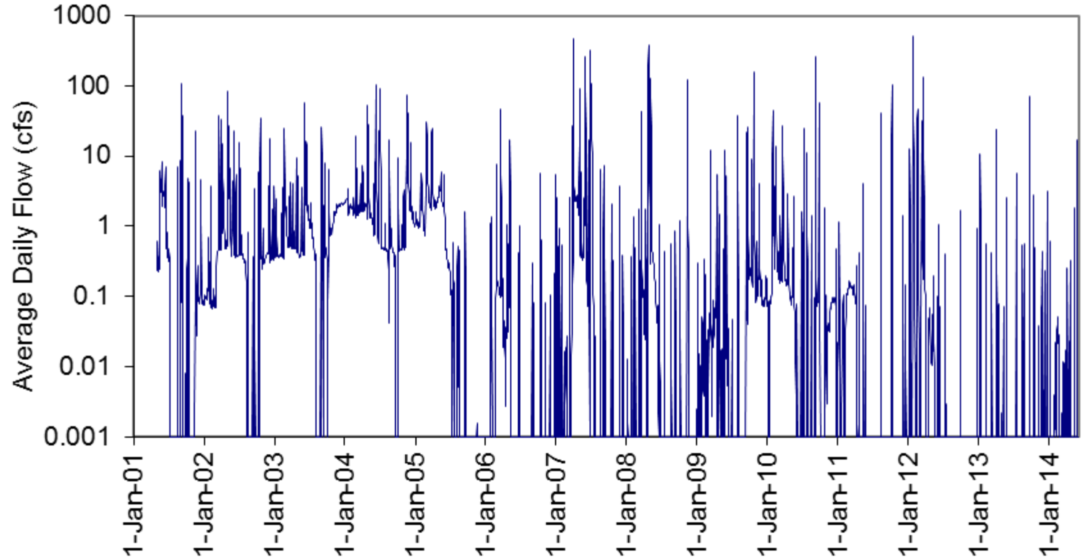

Figure C-12 Average daily flow at SF085 for May 1, 2001 through June 30, 2014. Missing daily estimates exist for February 23, 2005 and February 10-11, 2009.

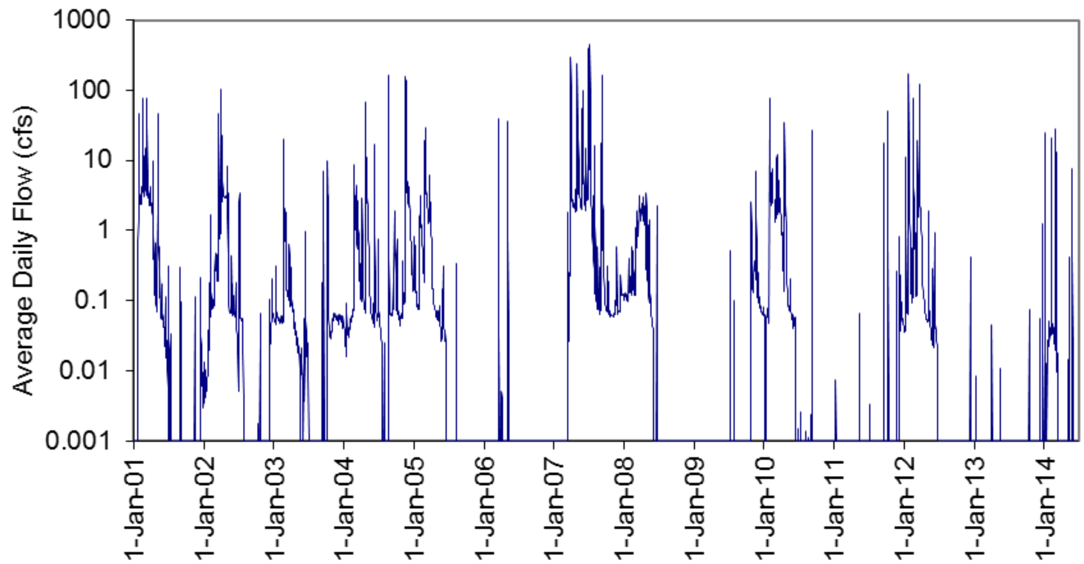

Figure C-13 Average daily flow at SP020 for January 3, 2001 through June 30, 2014. Missing daily estimates exist for April 24, 2004.