Microwatershed-Based Approach to Monitoring and Assessing Water Quality in the North Bosque River Watershed

Final Project Report

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TSSWCB 08-09

Contents

Tables

Figures

CHAPTER 1

Introduction

This project was designed to assess continuing 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). Along the NBR, Segments 1226 (North Bosque River) and 1255 (Upper North Bosque River) were included in the 1998 303(d) List as impaired under narrative water quality criteria related to nutrients and excessive growth of aquatic vegetation (Figure 1).

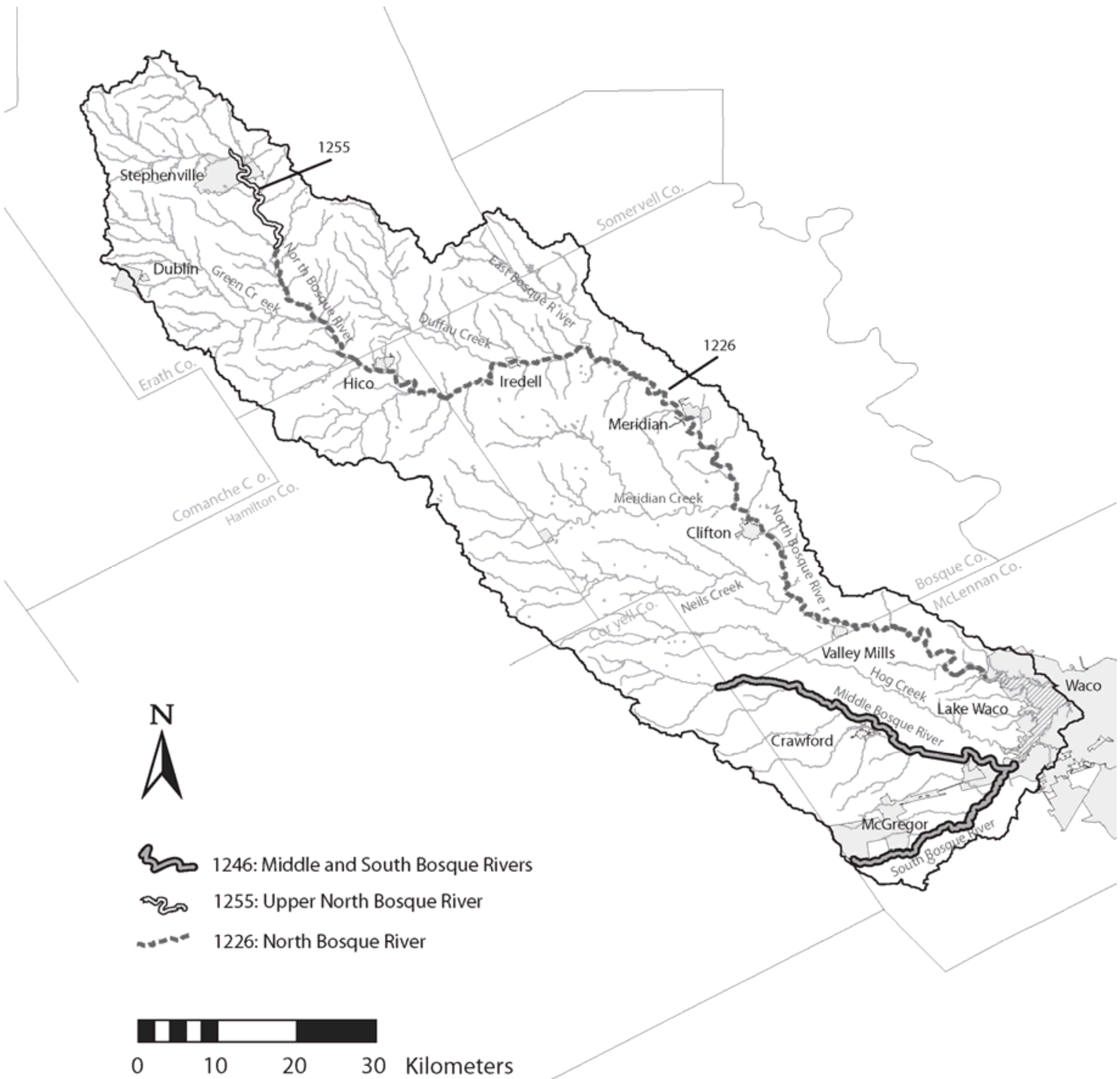

Figure 1 Classified stream segments within the Bosque River watershed.

Through the TMDL process, phosphorus was identified as the nutrient most often limiting aquatic plant growth, and dairy operations and municipal wastewater treatment facility (WWTF) effluents were considered the major controllable sources of phosphorus to the river. The 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 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 also 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,* and now this TSSWCB project 08-09, *Microwatershed-Based Approach to Monitoring and Assessing Water Quality in the NBR Watershed*. Under the current project, 18 microwatershed sites were monitored within the upper portion of the NBR watershed (Figure 2).

Sampling was emphasized within the upper portion of the NBR watershed, because almost all CAFO and AFO operations are found in this region of the watershed (Millican and McFarland, 2008). The headwaters of the NBR reside primarily in Erath County, the number one milk producing county in the state of Texas (USDA-AMS, 2009).

Within this report, water quality data from 2001 through 2009 were summarized for routine grab and storm samples from microwatershed sites. Trend analysis was used to assess improvements in water quality at the microwatershed scale with regard to the effectiveness of I-Plan activities toward meeting TMDL water quality goals.

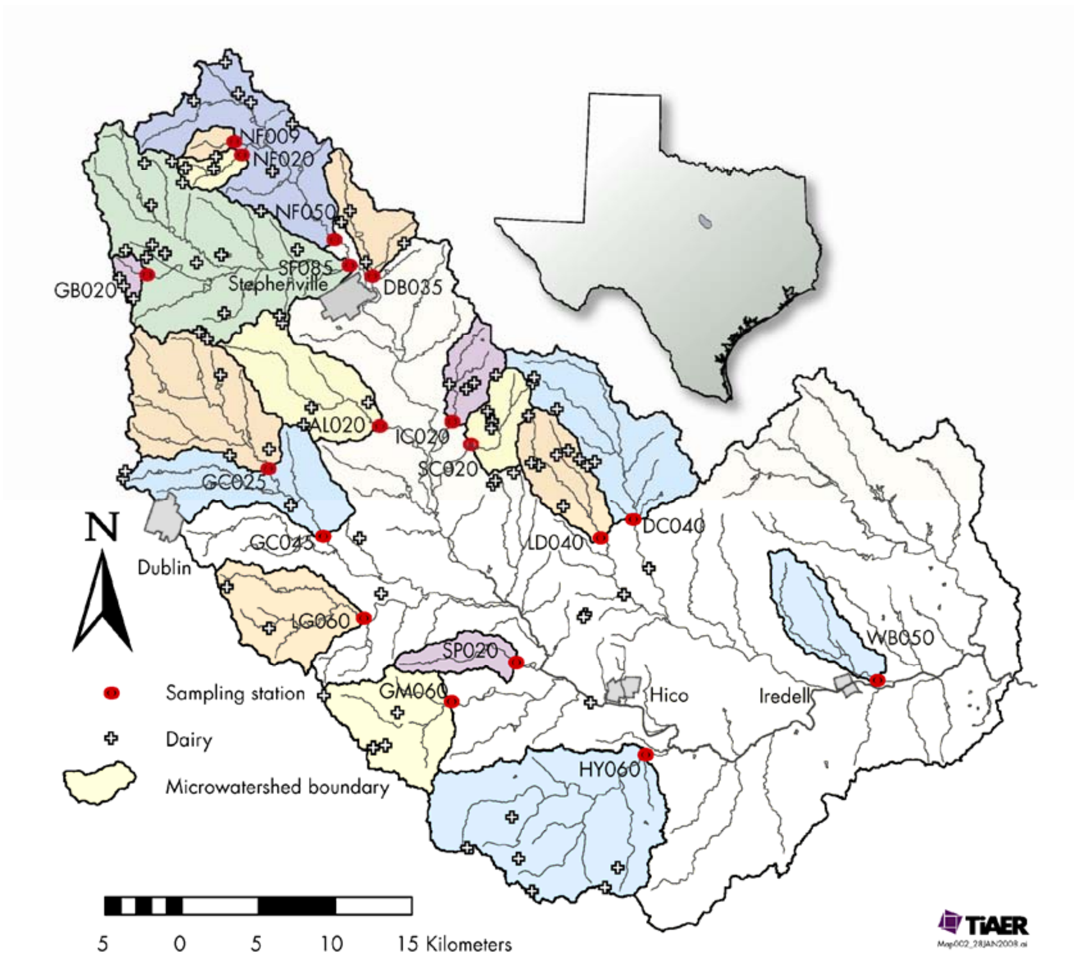

Figure 2 Microwatershed sampling sites and subwatershed delineations.

CHAPTER 2

Site Information

Location and Sampling History

Eighteen sampling sites were associated with the project with historical data for all but GC025 and WB050 extending back to at least 2001 (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
DC040	17607	Duffau Creek at FM 2481	16-Apr-01	7-May-01
GB020	17214	Unnamed tributary to Goose Branch between CR 541 and CR 297	11-May-95	5-May-95
GC025	20534	Green Creek downstream of FM 847	28-Jan-08	25-Jan-08
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
HY060	17611	Honey Creek at FM 1602	16-Apr-01	4-May-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]
SC020	17240	Sims Creek upstream of US 281	21-Sep-94	17-Jan-95[a]
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]
WB050	20533	Walker Branch at FM 927	28-Jan-08	26-Jan-08

a. Storm sampling suspended March 3, 1998 through May 3, 2001 at IC020 and SP020 and March 3, 1998 through May 12, 2001 at SC020.

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 waste application fields (WAFs). Although WAFs were a focus, sites were chosen to represent the diversity of land uses within the upper portion of the watershed ranging from primarily wood and rangeland, such as the land area above sites GM060 and SP020, to highly impacted microwatersheds, such as GB020 and NF020, to allow comparison between different land uses (Table 2). The most recent land-use information available was based on 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 compiled by TIAER from review of TCEQ permit information was used to supplement the satellite imagery classification. The location of animal WAFs was based on detailed information obtained in 2000 from TCEQ records that was updated in the fall of 2007. The updated information on WAFs includes milking and non-milking operations, although milking operations represent over 80 percent of the concentrated animal feeding operations (CAFOs) and animal feeding operations (AFOs) in the watershed. Cow density was estimated from TCEQ inspection records and other sources for some non-permitted facilities reviewed in the fall of 2007. Records from the Texas Department of Health were also used to determine which dairy operations were active and milking.

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). Information on animal waste application fields and estimated cow density represent values as of fall 2007 based on TCEQ records.

Site	Wood & Range (%)	Pasture (%)	Cropland (%)	Animal Waste App. Fields (%)	Urban or Impervious Surfaces (%)	Other (%)	Total Area (Hectares)	Estimated Cow Density (cows/ha)
AL020	31.9	45.0	7.8	11.7	2.8	0.8	4,720	0.49
DB035	23.3	45.6	11.3	14.3	3.5	2.0	2,130	0.58
DC040	51.8	27.0	5.6	13.8	1.3	0.4	6,250	0.44
GB020	25.1	22.6	5.8	40.0	4.7	1.8	440	6.71
GC025	26.5	55.3	9.8	5.8	1.6	0.9	6,610	0.33
GC045	31.1	49.1	8.6	7.8	2.4	0.9	11,900	0.60
GM060	55.9	35.8	1.1	5.8	1.1	0.3	4,410	0.34
HY060	63.6	28.4	2.6	4.2	0.7	0.4	11,800	0.50
IC020	36.7	35.1	6.7	19.3	1.7	0.5	1,740	1.28
LD040	33.2	26.9	7.2	31.3	0.3	1.0	2,960	1.54
LG060	38.9	40.2	8.6	10.3	1.0	1.0	4,260	0.77
NF009	30.8	49.8	2.7	13.5	2.8	0.4	520	0.38
NF020	19.6	33.7	2.4	41.3	1.9	1.0	800	2.15
NF050	23.4	47.8	7.4	17.7	2.8	0.8	8,370	0.47
SC020	44.5	27.5	5.2	20.3	2.0	0.5	1,900	0.21
SF085	28.2	37.7	11.8	16.7	4.5	1.1	12,900	0.82
SP020	65.0	33.1	1.3	0.0	0.3	0.2	1,560	0
WB050	77.2	20.3	1.9	0.0	0.3	0.3	2,220	0

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

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

Specific site descriptions are provided below by creek.

Alarm Creek

Site AL020 AL020 is an automated sampling site 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. Alarm Creek has been routinely monitored since May 2001.

Dry Branch

Site DB035 DB035 is an automated sampling site 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. Routine and storm sampling at DB035 was initiated in April 2002.

Duffau Creek

Site DC040 DC040 is an automated sampling site, located on Duffau Creek, at FM 2481, immediately northeast of Duffau, Texas in Erath County. An automated sampler was installed at the site in May 2001. The majority of land in the DC040 drainage area is classified as wood and range followed by improved pasture with some land used for WAFs.

Goose Branch

Sites GB020 GB020 is an automated sampling site 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 GC025 Site GC025 is an automated site located on Green Creek, 2.69 kilometers (1.7 miles) downstream of the confluence with Buck Creek on FM 847, south of Stephenville, Texas. Routine grab sampling began at this site in January 2008, while automated sampling began in April 2008. The main land use above GC025 is improved pasture followed by wood and range.

Site GC045 Site GC045 is an automated site, 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. Routine and storm sampling was initiated at GC045 in 2001.

Gilmore Creek

Site GM060 GM060 is an automated sampling site 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 Carleton, Texas. Land uses above GM060 are predominantly wood and range and improved pasture.

Honey Creek

Site HY060 HY060 is an automated sampling site located on Honey Creek, at FM 1602 approximately 4.7 kilometers (2.9 miles) southeast of Hico, in Hamilton County. The majority of the land above HY060 is designated as wood or range with some permanent pasture.

Indian Creek

Site IC020 IC020 is located near U.S. Highway 281, on Indian Creek, which discharges into the upper North Bosque River between Stephenville and Hico, Texas. Automated sampling was suspended from March 3, 1998 to May 3, 2001, while routine sampling was continued. 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 LD040 is an automated sampling site, located on Little Duffau Creek, at FM 1824, 2 km (1.2 miles) west of Duffau, Texas 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. Routine and storm sampling were initiated at LD040 in 2001.

Little Green Creek

Site LG060 LG060 is an automated sampling site, located on Little Green Creek, at FM 914, 3.2 kilometers (2.0 miles) south of Alexander, Texas. 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. Routine and storm sampling were initiated at LG060 in 2001.

North Fork

Sites NF009 and NF020 These automated sites are located in a microwatershed of 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, an automated sampling site, is located on the North Fork of the North Bosque River, at SH 108, approximately 1.6 km (1.0 mile) northwest of Stephenville. Sampling was initiated at NF050 in 1991 but was suspended in early 1997 until 2001. 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.

Sims Creek

Site SC020 Site SC020 is located near U.S. Highway 281 on Sims Creek. Sims Creek is just south of Indian Creek within the upper portion of the North Bosque River watershed. Automated storm sampling at SC020 was suspended from March 3, 1998 to May 12, 2001. Routine grab sampling continued throughout the monitoring period. The majority of the land area above SC020 is wood and range, although a fair amount of land is also associated with improved pasture or WAFs.

South Fork

Site SF085 Site SF085 is an automated sampling site 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. Automated sampling was suspended from March 3, 1998 to May 3, 2001. Routine grab sampling continued throughout the monitoring period. 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.

Walker Branch

Site WB050 Site WB050 is located on Walker Branch, 1.21 kilometers (0.75 miles) upstream of the confluence with the North Bosque River on FM 927, east of Iredell. Routine grab and automated sampling began at this site in January 2008. Wood and range are the main land uses above WB050 with some pasture. No animal waste fields are located in this microwatershed.

CHAPTER 3

Methods

Storm Sampling

Storm sampling was accomplished using an Isco 4230 or 3230 bubbler type flow meter in conjunction with an Isco 3700 sampler. Each flow meter recorded water level at 5-min intervals by measuring the pressure required to force an air bubble through a 3-mm (0.125-inch) polypropylene tube. The automated sampler would begin sampling when a set rise in water level occurred. Once activated the sampler would retrieve one-liter sequential samples. The typical sampling sequence 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 about 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 when 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 with the current project, only selected events rather than all events were monitored. Due to relatively dry weather conditions in late 2008 through mid-2009, most storm events that occurred were monitored and only a few relatively small events were omitted.

Grab Sampling

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 December 2009. Routine grab samples were collected only when flow was present. Samples were not collected at sites that were dry or pooled (see Adams and McFarland, 2009). Samples were collected at a depth of about 0.25 to 0.5 ft (0.08 to 0.15 meters). 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, 2008a).

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 ammonia-nitrogen (NH_3-N) and nitrite-nitrogen plus nitrate-nitrogen (NO_2-N+NO_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 orthophosphate-phosphorus (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 total phosphorus (total-P) and total Kjeldahl nitrogen (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.

While routine grab samples for lab analysis were being collected, measurements were taken and recorded *in-situ* for water temperature, dissolved oxygen, pH, and specific conductance (conductivity) using a YSI multiprobe instrument.

Constituent and Analysis Methods

Routine grab and storm samples were analyzed for NH_3-N, NO_2-N+NO_3-N, TKN, PO_4-P, total-P , and TSS were evaluated for both the (Table 3). In non-direct data collected prior to 2002, only fecal coliform (FC) was analyzed for bacteria with grab samples. From February 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 March 2004, FC was discontinued, and the analysis method for *E. coli* was changed to the IDEXX Colilert method.

Table 3 Analysis methods and method detection limits for water quality constituents

Constituent	Method	Range of MDLs[a]	Range of TCEQ AWRLs or Project LOQs[b]
Field Measurements			
Conductivity	EPA[c] 120.1	not applicable	not applicable
Dissolved oxygen	EPA 360.1	not applicable	not applicable
pH	EPA 150.1	not applicable	not applicable
Water temperature	EPA 170.1	not applicable	not applicable
Laboratory Measurements			
Ammonia-nitrogen	EPA 350.1 or SM[d] 2540 D-98	0.004 - 0.031 mg/L	0.02 – 0.1 mg/L
Escherichia coli	SM 9222G/9223B[e]	1 - 2 colonies/100 mL[f]	1 colony/100 mL
Fecal coliform	SM 9222D	1 colony/100 mL	1 colony/100 mL
Nitrite-nitrogen+nitrate-nitrogen	EPA 353.2 or SM 4500-NO3-F-00	0.006 - 0.056 mg/L	0.04 - 0.05 mg/L
Total Kjeldahl nitrogen	EPA 351.2 or SM 4500-NH3 G-97	0.022 - 0.188 mg/L	0.20 mg/L
Orthophosphate-phosphorus	EPA 365.2 or SM 18th ed 4500-PE	0.0009 - 0.004 mg/L	0.005 mg/L[g]
Total phosphorus	EPA 365.4	0.017 - 0.082 mg/L	0.06 mg/L
Total suspended solids	EPA 160.2 or SM 2540 D-98	2 - 8 mg/L	4 mg/L

a. MDLs were periodically updated by TIAER's laboratory. A range is presented showing the lowest and highest MDLs used during the reporting period (January 2001 – December 2009).

b. Source: Listing of *Ambient Water Quality Reporting Limits for Texas Surface Water Quality Monitoring Programs* (TCEQ, 2008b).

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*, online or 18th Edition (APHA, 1992).

e. Most probable number (MPN) or IDEXX method for *E. coli* was implemented in April 2004.

f. Results from the IDEXX method are reported as MPN/100 mL whereas plating technique results are reported as colonies/100 mL. In this report, data for all *E. coli* results are presented in units of colonies/100 mL regardless of the analysis method.

g. 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 projects due to the TMDLs for soluble reactive phosphorus for Segments 1226 and 1255.

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). Prior to 2003, method detection limits (MDLs) were used as the reporting limit. Starting in 2003, some TIAER projects, but not all, started to require ambient water reporting limits (AWRLs) set by the TCEQ as data reporting limits. TIAER has continued to evaluate MDLs as part of good laboratory practice, but has shifted to using AWRLs for most projects unless another reporting limit is specified by the project sponsor for a constituent.

Statistical Evaluation Methods

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 2009 representing a period after initiation of the I-Plan for the North Bosque TMDLs.

Trend Analysis Using Kendall's Tau

To evaluate post-TMDL trends in storm data collected from 2001 through 2009, trend analysis was performed on volume-weighted storm event data summarized on a monthly basis. 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 in Reckhow et al. (1993). The Kendall's tau test was 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 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):

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

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 2009 indicated several significant trends in water quality (Tables 4-9). Downward trends in PO_4-P were indicated at sites GM060 and IC020 and increasing trends at sites LD040, NF009 and SF085 (Table 4). For total-P, downward trends were indicated at sites GB020, GM060, IC020 and NF020 and increasing trends at sites NF009 and SF085 (Table 5). Decreasing trends in NH_3-N were indicated at sites IC020, NF020 and SC020 (Table 6). Decreasing trends in NO_2-N+NO_3-N were detected at sites GM060, IC020, NF020 and SP020 and increasing trends at NF009 (Table 7). Decreasing trends in TKN were indicated at sites GM060, HY060, IC020, NF020 and SC020 (Table 8). Decreasing trends in TSS were indicated at DB035 and NF020 and increasing trends at NF009 and SF085 (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	Slope (% change/yr)
AL020	Sep 2001-Oct 2009	-0.075	0.4295	
DB035	Feb 2002- Oct 2009	0.115	0.2255	
DC040	May 2001- Oct 2009	0.107	0.2250	
GB020	Jan 2001- Oct 2009	-0.230	0.0534	
GC045	May 2001- Oct 2009	0.017	0.8794	
GM060	Aug 2001- Oct 2009	-0.483	0.0000**	-3.61
HY060	May 2001- Oct 2009	-0.032	0.7619	
IC020	May 2001- Oct 2009	-0.187	0.0443*	-0.45
LD040	Aug 2001- Oct 2009	0.281	0.0044**	0.49
LG060	Jan 2001- Oct 2009	-0.163	0.1728	
NF009	Jan 2001- Oct 2009	0.373	0.0001**	0.73
NF020	Feb 2001- Oct 2009	-0.038	0.6843	
NF050	May 2001- Oct 2009	0.020	0.8450	
SC020	May 2001- Oct 2009	-0.063	0.4735	
SF085	May 2001- Oct 2009	0.157	0.0289*	0.32
SP020	May 2001- Oct 2009	-0.042	0.6697	

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	Slope (% change/yr)
AL020	Sep 2001-Oct 2009	-0.123	0.1975	
DB035	Feb 2002- Oct 2009	-0.004	0.9694	
DC040	May 2001- Oct 2009	0.136	0.1228	
GB020	Jan 2001- Oct 2009	-0.264	0.0267*	-0.49
GC045	May 2001- Oct 2009	-0.013	0.9137	
GM060	Aug 2001- Oct 2009	-0.416	0.0001**	-1.80
HY060	May 2001- Oct 2009	0.109	0.2890	
IC020	May 2001- Oct 2009	-0.279	0.0027**	-0.55
LD040	Aug 2001- Oct 2009	0.190	0.0523	
LG060	Jan 2001- Oct 2009	-0.092	0.4432	
NF009	Jan 2001- Oct 2009	0.238	0.0132*	0.50
NF020	Feb 2001- Oct 2009	-0.284	0.0022**	-0.57
NF050	May 2001- Oct 2009	0.131	0.1914	
SC020	May 2001- Oct 2009	-0.023	0.7986	
SF085	May 2001- Oct 2009	0.189	0.0083**	0.41
SP020	May 2001- Oct 2009	-0.027	0.7890	

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.

Station	Period Evaluated	Kendall Test Statistic	p-value	Slope (% change/yr)
AL020	Sep 2001-Oct 2009	0.034	0.6787	
DB035	Feb 2002- Oct 2009	-0.177	0.0623	
DC040	May 2001- Oct 2009	-0.122	0.1671	
GB020	Jan 2001- Oct 2009	-0.049	0.6909	
GC045	May 2001- Oct 2009	-0.141	0.1934	
GM060	Aug 2001- Oct 2009	-0.093	0.3733	
HY060	May 2001- Oct 2009	-0.122	0.2364	
IC020	May 2001- Oct 2009	-0.324	0.0005**	-1.26
LD040	Aug 2001- Oct 2009	0.044	0.6575	
LG060	Jan 2001- Oct 2009	-0.148	0.2166	
NF009	Jan 2001- Oct 2009	-0.118	0.2213	
NF020	Feb 2001- Oct 2009	-0.210	0.0240*	-0.85
NF050	May 2001- Oct 2009	-0.125	0.2134	
SC020	May 2001- Oct 2009	-0.255	0.0034**	-0.63
SF085	May 2001- Oct 2009	0.073	0.3088	
SP020	May 2001- Oct 2009	-0.021	0.8343	

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.

Station	Period Evaluated	Kendall Test Statistic	p-value	Slope (% change/yr)
AL020	Sep 2001-Oct 2009	0.030	0.7531	
DB035	Feb 2002- Oct 2009	-0.089	0.3533	
DC040	May 2001- Oct 2009	0.017	0.8470	
GB020	Jan 2001- Oct 2009	-0.151	0.2062	
GC045	May 2001- Oct 2009	0.120	0.2690	
GM060	Aug 2001- Oct 2009	-0.314	0.0024**	-1.92
HY060	May 2001- Oct 2009	-0.119	0.2480	
IC020	May 2001- Oct 2009	-0.222	0.0169*	-0.68
LD040	Aug 2001- Oct 2009	0.055	0.5809	
LG060	Jan 2001- Oct 2009	-0.234	0.0500	
NF009	Jan 2001- Oct 2009	0.211	0.0277*	0.96
NF020	Feb 2001- Oct 2009	-0.269	0.0039**	-0.77
NF050	May 2001- Oct 2009	-0.085	0.3985	
SC020	May 2001- Oct 2009	-0.150	0.0.867	
SF085	May 2001- Oct 2009	0.018	0.7992	
SP020	May 2001- Oct 2009	-0.207	0.0350*	-0.70

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.

Station	Period Evaluated	Kendall Test Statistic	p-value	Slope (% change/yr)
AL020	Sep 2001-Oct 2009	-0.082	0.3903	
DB035	Feb 2002- Oct 2009	-0.137	0.1493	
DC040	May 2001- Oct 2009	0.066	0.4552	
GB020	Jan 2001- Oct 2009	-0.076	0.5321	
GC045	May 2001- Oct 2009	-0.099	0.3626	
GM060	Aug 2001- Oct 2009	-0.504	0.0000**	-1.63
HY060	May 2001- Oct 2009	-0.275	0.0072**	-0.83
IC020	May 2001- Oct 2009	-0.335	0.0003**	-0.59
LD040	Aug 2001- Oct 2009	0.037	0.7128	
LG060	Jan 2001- Oct 2009	-0.160	0.1819	
NF009	Jan 2001- Oct 2009	-0.032	0.7463	
NF020	Feb 2001- Oct 2009	-0.267	0.0041**	-0.60
NF050	May 2001- Oct 2009	0.103	0.3067	
SC020	May 2001- Oct 2009	-0.242	0.0055**	-0.76
SF085	May 2001- Oct 2009	0.078	0.2784	
SP020	May 2001- Oct 2009	0.037	0.6274	

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.

Station	Period Evaluated	Kendall Test Statistic	p-value	Slope (% change/yr)
AL020	Sep 2001-Oct 2009	-0.064	0.5046	
DB035	Feb 2002- Oct 2009	-0.215	0.0236*	-1.05
DC040	May 2001- Oct 2009	0.156	0.0772	
GB020	Jan 2001- Oct 2009	0.018	0.8871	
GC045	May 2001- Oct 2009	0.066	0.5439	
GM060	Aug 2001- Oct 2009	-0.174	0.0944	
HY060	May 2001- Oct 2009	0.030	0.7764	
IC020	May 2001- Oct 2009	-0.100	0.2826	
LD040	Aug 2001- Oct 2009	-0.158	0.1083	
LG060	Jan 2001- Oct 2009	-0.187	0.1183	
NF009	Jan 2001- Oct 2009	0.195	0.0426*	0.70
NF020	Feb 2001- Oct 2009	-0.205	0.0273*	-1.09
NF050	May 2001- Oct 2009	0.103	0.3067	
SC020	May 2001- Oct 2009	-0.166	0.0581	
SF085	May 2001- Oct 2009	0.219	0.0023**	1.31
SP020	May 2001- Oct 2009	-0.115	0.2416	

Of the 16 sites evaluated for trends, 5 sites (AL020, DC040, GC045, LG060 and NF050) showed no trends, positive or negative; 8 sites (DB035, GB020, GM060, HY060, IC020, NF020, SC020 and SP020) showed negative trends for various constituents; and 3 sites (LD040, NF009 and SF085) showed positive trends for various constituents. No single site showed both positive and negative trends if more than one constituent was significant. For phosphorus, the primary nutrient of interest, four sites (GB020, GM060, IC020 and NF020) indicated negative trends and three sites (LD040, NF009 and SF085) indicated positive trends for either PO_4-P or total-P. For nitrogen, six sites (GM060, HY060, IC020, NF020, SC020 and SP020) indicated negative trends for at least one nitrogen constituent and only one site (NF009) showed a positive trend for NO_2-N+NO_3-N. For TSS, two sites (DB035 and NF020) had negative trends and two sites (NF009 and SF085) had positive trends.

Trend Analysis Discussion

As found in other reports (e.g., Millican and McFarland 2008), decreasing trends in phosphorus occurred at microwatershed sites associated with higher rates of participation in the manure composting program. Sites GB020, IC020 and NF020 showed some of the highest rates of participation of the 16 sites evaluated, when the amount of manure hauled was normalized on a cow and per unit area basis (Figure 3). In contrast, site LD040, which had a fairly large total amount of manure hauled (Figure 4), showed increasing trends in P, but also indicated much lower normalized amounts of manure hauled than sites that showed decreasing trends (Figure 3).

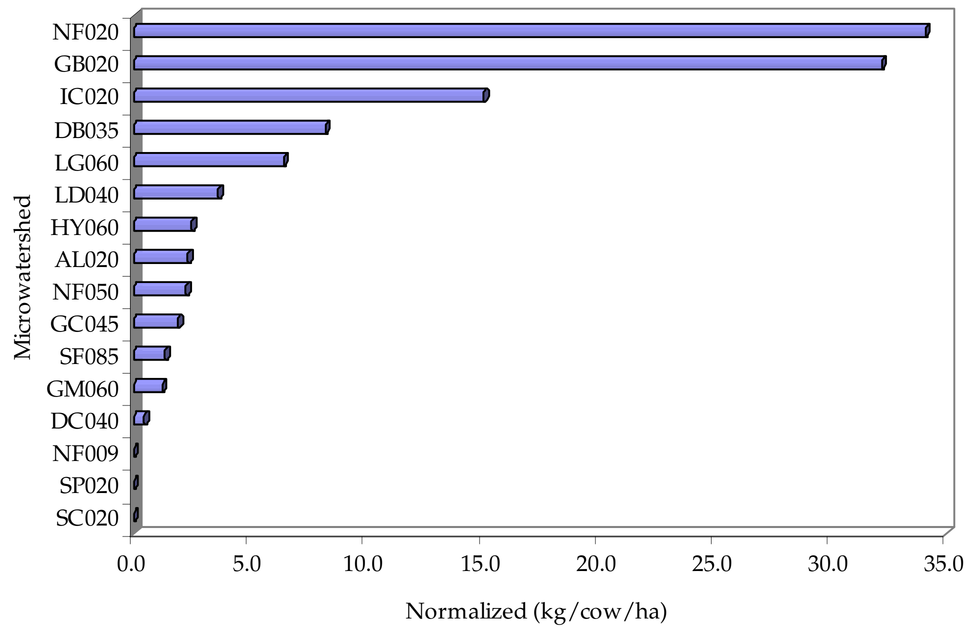

Figure 3 Manure hauled normalized for drainage area size and average cow numbers.

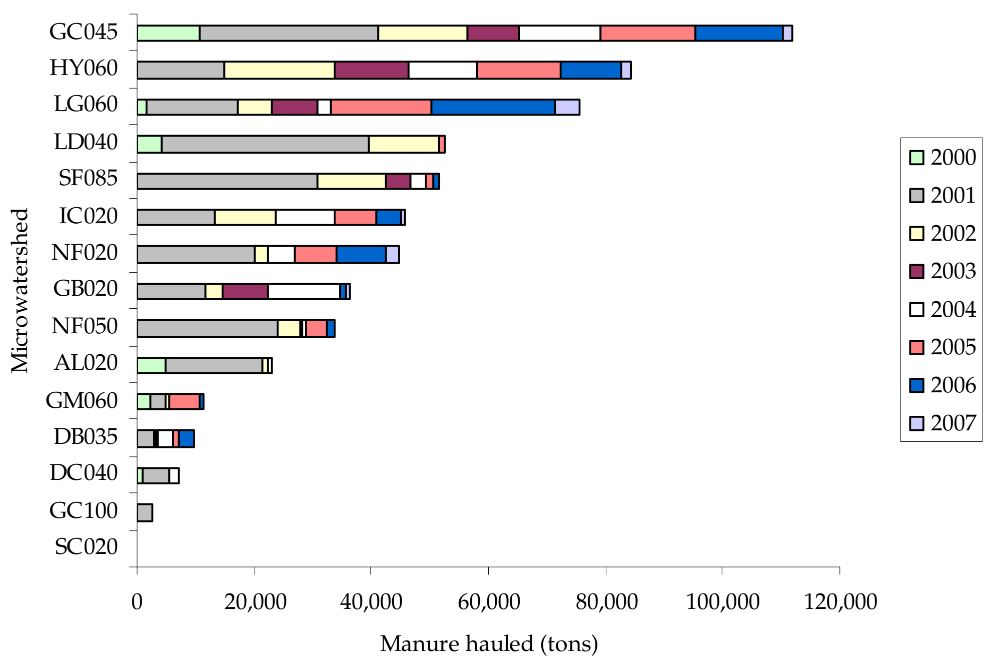

Figure 4 Manure hauled to composting facilities from within microwatershed drainage areas between November 2000 and February 2007. Note: The manure haul-off program ended in February 2007.

While it is not known specifically why increasing trends in P were noted at site LD040, there were some indications that these increases may in part be associated with wastewater discharges from ponds or dewatering equipment rather than solely rainfall-runoff. In 2007 when flooding conditions occurred in many portions of the watershed, several samples at LD040 had relatively high ammonia concentrations (> 4 mg/L), which can be indicative of wastewater.

Land-use changes may also be influencing the change in water quality at LD040. A comparison of land-use data from the late 1990s with data from the mid-2000s indicates a 23 percent increase in land associated with improved pasture and cropland with a commensurate decrease in land associated with wood and rangeland (Millican and McFarland, 2008). The other two sites that showed increasing trends in P (NF009 and SF085) also showed a 14 to 17 percent increase in improved pasture and cropland with a corresponding decrease in land associated with wood and range. While fertilizer sales for the area have decreased notably over time (Figure 5), it is possible that more land in these microwatersheds is receiving fertilizer, thus, increasing the cumulative area impacted by rainfall-runoff events even if less fertilizer is applied per acre.

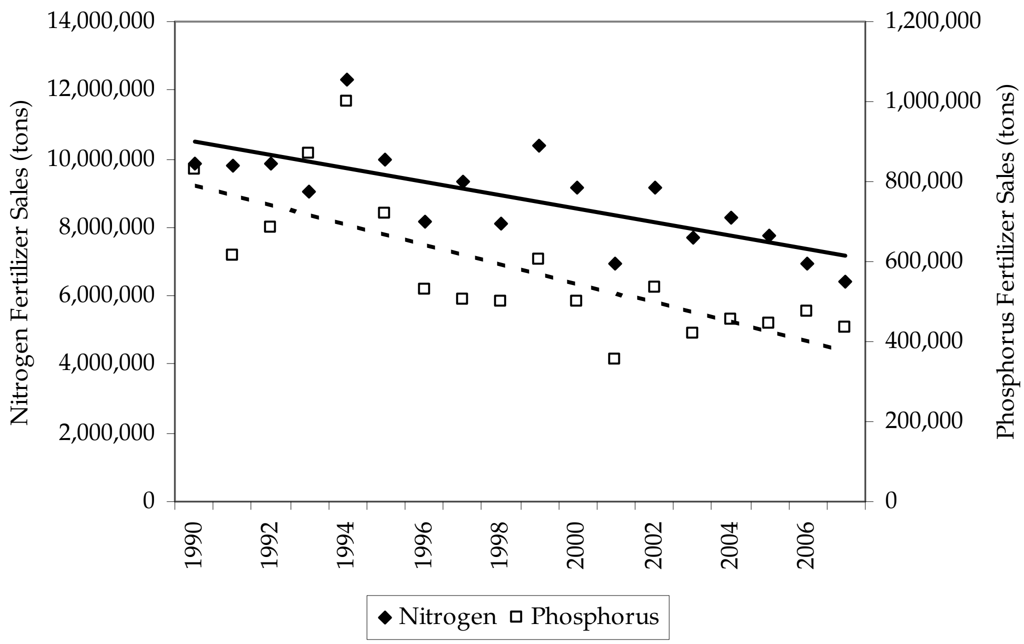

Figure 5 Annual sale of commercial fertilizer for Erath County for 1990-2007. Phosphorus represented as elemental P rather than P_2O_5. Source: The Association of American Plant Food Control Officials (AAPFCO).

Of the sites showing increasing trends in P, only site NF009 showed a corresponding increase in N (NO_2-N+NO_3-N), which might be associated with increased fertilizer runoff. Both sites NF009 and SF085 showed increasing trends in total-P as well as in TSS indicating more particulate movement. This increase in particulate movement may be associated with land-use changes that may be increasing erosion. At LD040 only PO_4-P, representing the soluble portion of total-P, showed any trend (negative or positive) for the constituents measured indicating that particulate movement was not as large a factor in the measurement of increased P losses for this microwatershed.

A fourth site with decreasing trends in P was GM060. The Gilmer Creek microwatershed is not associated with a large number of animal feeding operations or large quantities of manure haul-off, but has been the focus of some water quality management plans (WQMPs) through the TSSWCB focusing on overgrazing and brush control. There are indications that improved grazing management practices and reduced stocking rates may be responsible for decreasing trends in P noted in this microwatershed.

As discussed in previous reports (e.g., Millican and McFarland, 2008), weather conditions play a large role in the movement of nonpoint source pollution. The amount of rainfall can vary greatly from year to year (Figure 6) as well as the associated runoff throughout the watershed (Figures 7 and 8). Using 2001 as a cutoff based on when the I-Plan was approved, precipitation and runoff appeared to be less variable than during the pre than post-TMDL period, although both periods have obvious years of drought (1999 and 2005) and flooding (1997 and 2007).

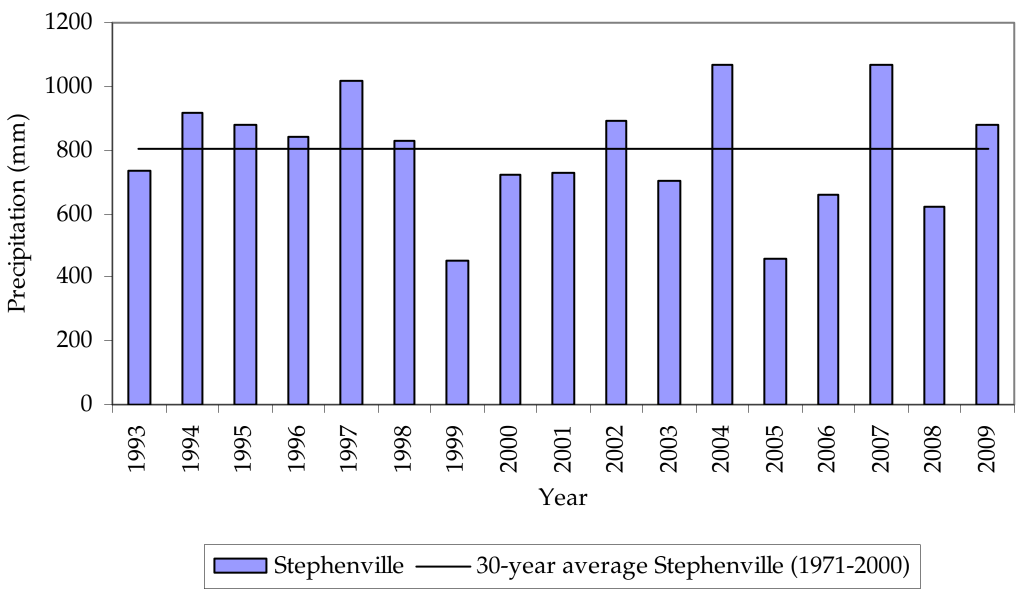

Figure 6 Annual precipitation at Stephenville, Texas. Data Source: Texas AgriLife Research and Extension Center.

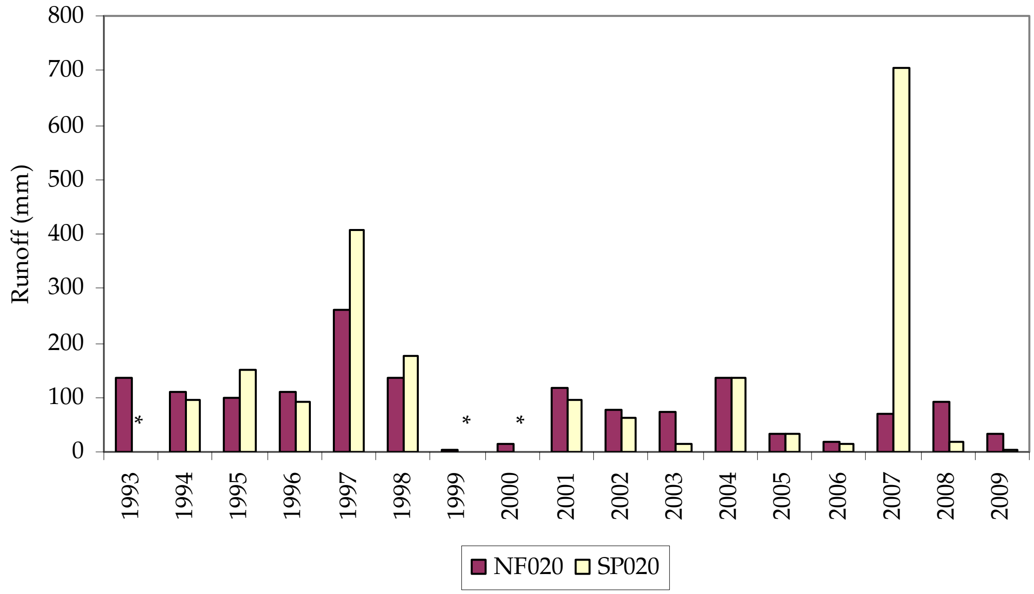

Figure 7 Estimated annual runoff associated with sites NF020 and SP020. Asterisks for SP020 in 1993, 1999 and 2000 indicate years with incomplete data, thus, no annual value presented.

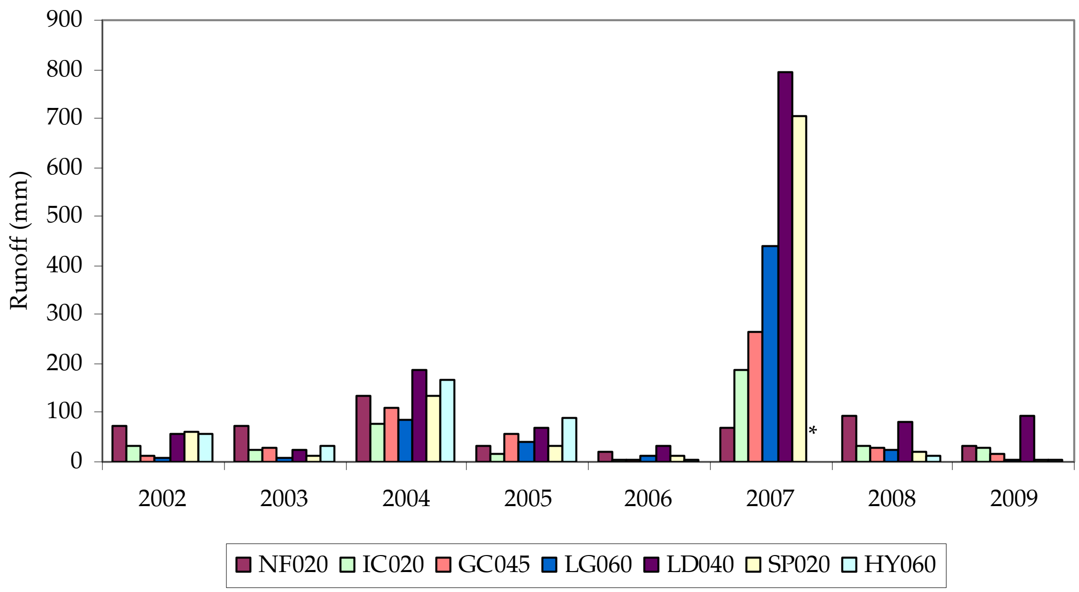

Figure 8 Estimated annual runoff for selected microwatershed sites throughout the upper North Bosque River watershed for 2002 through 2009. Sites are ordered in general from north to south within the watershed. The asterisk in 2007 for HY060 indicated no data as annual runoff could not be determined due to flooding conditions that disabled the site for almost 20 days.

Even for years that appear to show similar rainfall amounts, such as 2004 and 2007 (Figure 6), the actual site-specific runoff can be quite variable across the watershed (Figure 8) depending on how much rain comes with any one storm and antecedent rainfall conditions. In 2004, rainfall was more spread out temporally and spatially through the watershed than in 2007, thus less runoff was noted at most sites in 2004 than in 2007 (Figure 8). In 2007, heavier rains were more prevalent below than above Stephenville leading to a large spatial divergence in runoff between sites (Figure 8).

While large changes in water quality are not being measured in-stream, there are indications that I-Plan activities, such as the manure compositing program, are having a positive impact on water quality. Although the composting program is no longer active, six of the seven composting facilities initiated with the program were active in 2009 and most updated CAFO permits note manure composting as an option for manure disposal. Other I-Plan activities, such as revised animal feeding operations (AFO) and confined animal feeding operation (CAFO) rules leading to development and implementation of nutrient management plans (NMPs), are expected to take more time before in-stream success is measured. A lag time exists between the I-Plan adoption and the planning and implementation time needed for these activities. Amendments to the CAFO rules were not adopted until 2004 and became effective upon reissuance of new or amended permits. This started what can be a relatively slow process of developing and certifying comprehensive nutrient management plans (CNMPs), which peaked with 34 CNMPs certified in FY07. Prior to FY07 only 12 CNMPs had been certified and an additional 7 were certified in FY08. These CNMPs include the NMP for waste application fields as well as additional nutrient controls, such as feed management and storage and handling practices for manure and wastewater. In 2008, nearly 50 CAFO permits were under technical review by the TCEQ. These new and amended permits, based on the revised CAFO rules, require an increase in the margin of safety for wastewater retention structures from a 25-yr/24-hr rainfall event to a 25-yr/10-day event, the implementation of CNMPs, and installation of vegetative buffer and filter strips on the edges of land application areas as well as other requirements. While many of these permits are now approved and it is anticipated that many AFO and CAFO operators have been proactive in implementing practices, there is still an expected lag time between full implementation of all adopted practices before an in-stream effect is produced that is measureable.

The lag time between the implementation of land management practices and the measured reduction of in-stream soluble P is expected to take years to decades, primary due to the interaction of soluble P with soils (Meals et al., 2010). Runoff losses of soluble P are strongly related to soil P concentrations (e.g., Sharpley, 1995; Sharpley et al., 1999) and even when P inputs are greatly reduced or ceased; it may take many years to reduce P from these soils to notably impact runoff (e.g., Zhang et al., 2004; McFarland and Hauck, 2004). Weather influences the length of this lag time by influencing crop yield and, thus, the amount of P removed from the soil. For example, if P is applied assuming normal growth conditions and a drought ensues greatly reducing yields, residual P from drought years may be associated with runoff in future years. Lag time is an important factor in considering expectations for NPS management efforts.

CHAPTER 5

Conclusions

Measured reductions of in-stream P are occurring at microwatershed sites within the North Bosque River watershed, but to date most of these reductions have been relatively small and primarily associated with the haul-off of manure from the manure composting program. While the manure composting program is no longer active, it is anticipated that the impacts from this program will continue as dairy producers continue to use composting as an option for manure disposal. Other activities associated with the North Bosque River TMDL I-Plan have had a slower implementation time, and thus, a lag time is expected as these practices, such as CNMPs, are put into practice. Studies outside the North Bosque watershed have indicated that it may take years to decades before notable decreases in soluble P are seen within the stream system, primarily because the runoff of dissolved P is strongly controlled by soil P concentrations (Meals et al., 2010). Even as appropriate land management practices are implemented to reduce the runoff of soluble P, legacy or residual P may take years to “mine” or harvest from the land. Lag times between implementation of management practices and in-stream response should be recognized and communicated as part of setting reasonable expectations for water quality improvements (Clausen, et al., 1992; Meals, et al., 2010).

References

Adams, T. and A. McFarland. 2009. Semiannual Water Quality Report for the North Bosque River Watershed Monitoring Period: January 1, 2002 – December 31, 2008. Texas Institute for Applied Environmental Research, Tarleton State University, Stephenville, Texas, TR0903.

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

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

Clausen, J.C., D.W. Meals and E.A. Cassel. 1992. Estimation of lag time for water quality response to BMPs, pp. 173-180. In: Proceedings of the National RCWP Symposium, Orlando, Florida.

DiLuzio, M., R. Srinivasan, J.G. Arnold, and S.L. Neithsch. 2002. Soil and Water Assessment Tool. ArcView GIS Interface Manual: Version 2000. GSWRL Report 02-03, BRC Report 02-07, Published by the Texas Water Resources Institute TR-103, College Station, Texas, 346 p.

EPA, United States Environmental Protection Agency. 1983. Methods for Chemical Analysis of Water and Wastes. Environmental Monitoring and Support Laboratory, Office of Research and Development, US-EPA, Cincinnati, Ohio. EPA-600/4-79-020, Revised March 1983.

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

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

Helsel, D.R. and R.M. Hirsch, 2002. Chapter A3. Statistical Methods in Water Resources. In Techniques of Water-Resources Investigations, Book 4, Hydrologic Analysis and Interpretation. United States Geological Survey, Arlington, Virginia.

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

McFarland, A.M.S., and L.M. Hauck. 2004. Controlling phosphorus in runoff from long term dairy waste application fields. Journal of the American Water Resources Association 40:1293-1304.

McFarland, A. and J. Millican. 2006 Assessment of Preexisting and Post Implementation Effects for the North Bosque River Watershed: Clean Water Act Section 319 Report. Texas Institute for Applied Environmental Research, Tarleton State University, Stephenville, Texas, TR0602.

Meals, D.W., S.A. Dressing and T.E. Davenport. 2010. Lag time in water quality response to best management practices: A review. Journal of Environmental Quality 39:85-96.

Millican, J. and A. McFarland. 2008. Extending TMDL Efforts in the North Bosque River Watershed: Assessment Data through 2007. Final Project Report for the Texas Soil and Water Conservation Board by the Texas Institute for Applied Environmental Research, Tarleton State University, Stephenville, Texas, TR0802.

Millican, J. and A. McFarland. 2007. Extending TMDL Efforts in the North Bosque River Watershed: Assessment Data through 2006. Interim Project Report for the Texas Soil and Water Conservation Board by the Texas Institute for Applied Environmental Research, Tarleton State University, Stephenville, Texas, TR0702.

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

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

Sharpley, A.N. 1995. Soil phosphorus dynamics: agronomic and environmental impacts. Ecological Engineering 5(2-3):261-279.

Sharpley, A.N, W.J. Gburek, G. Folmar and H.B. Pionke. 1999. Sources of phosphorus exported from an agricultural watershed in Pennsylvania. Agricultural Water Management 41(2):77-89.

Stein, S.K. 1977. Calculus and Analytic Geometry. 2nd ed. McGraw-Hill Book Company, New York, New York.

TCEQ, Texas Commission on Environmental Quality. 2008a. Surface Water Quality Monitoring Procedures, Volume 1. TCEQ, Monitoring Operations Division, Austin, Texas (RG-415).

TCEQ, Texas Commission on Environmental Quality. 2008b. Ambient Water Quality Reporting Limits (AWRLs) for Texas Surface Water Quality Monitoring Programs (Last Revised March 2008) [Online]. Available at http://www.tceq.state.tx.us/assets/public/compliance/monops/crp/ QA/awrlmaster.pdf (verified June 24, 2009).

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, TMDL Team, Austin, Texas and TSSWCB TMDL Team, Temple, Texas (December 2002).

TNRCC, Texas Natural Resource Conservation Commission. 2001. Two Total Maximum Daily Loads for Phosphorus in the North Bosque River for Segments 1226 and 1255. Strategic Assessment Division, TMDL Team, TNRCC, Austin, Texas (adopted February 2001; approved by EPA December 2001).

TNRCC, Texas Natural Resource Conservation Commission. 2000. Texas Surface Water Quality Standards, Chapter 307, Texas Administrative Code 307.1 - 307.10. TNRCC, Austin, Texas (effective 17 August 2000).

USDA-AMS, United States Department of Agriculture Agricultural Marketing Service. 2009. The Market Administrator's Report: Southwest Marketing Area; Vol. XXXV, No. 7 (July 2009).

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

Zhang, T.Q., A.F. MacKenzie, B.C. Liang, and C.F. Drury. 2004. Soil test phosphorus and phosphorus fractions with long-term phosphorus addition and depletion. Soil Science Society of America Journal 68:519-528.

APPENDIX A

Summary Statistics for Routine Grab Samples

All data analyses represent grab samples collected between January 1, 2001 and December 31, 2009. The exact date range of samples evaluated will vary by site based on monitoring history.

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

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.184	0.113	0.194	0.001	0.887	97
Total-P (mg/L)	0.34	0.25	0.35	0.03	2.59	96
NH_3-N (mg/L)	0.082	0.050	0.085	0.010	0.401	97
NO_2-N + NO_3-N (mg/L)	0.733	0.187	1.10	0.008	4.88	97
TKN (mg/L)	1.11	1.00	0.70	0.10	4.44	97
TSS (mg/L)	26	8	56	1	422	97
Water Temp. (°C)	16.8	17.3	6.6	2.0	30.9	97
Conductivity (µmhos/cm)	1070	1020	590	97	2610	97
DO (mg/L)	7.1	6.7	3.1	1.2	13.4	97
pH (standard units)	7.9	7.9	0.3	7.4	9.0	97
Fecal Coliform (colonies/100ml)	3100	350	13000	12	69000	29
Escherichia coli (colonies/100ml)	2000	230	8400	3	54000	84

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

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.502	0.468	0.324	0.058	1.50	56
Total-P (mg/L)	0.69	0.65	0.41	0.03	1.70	56
NH_3-N (mg/L)	0.127	0.058	0.175	0.007	0.733	56
NO_2-N + NO_3-N (mg/L)	1.41	0.979	1.64	0.015	6.03	56
TKN (mg/L)	1.70	1.56	0.75	0.25	4.22	56
TSS (mg/L)	19	11	27	2	144	56
Water Temp. (°C)	16.1	16.1	5.9	6.2	26.5	56
Conductivity (µmhos/cm)	1040	990	552	231	2350	56
DO (mg/L)	9.4	9.3	3.3	3.8	16.5	56
pH (standard units)	8.0	8.0	0.2	7.7	8.5	56
Fecal Coliform (colonies/100ml)	1300	270	3200	52	14000	22
Escherichia coli (colonies/100ml)	5700	320	24000	22	140000	53

Table A-3 Routine grab sample summary statistics for site DC040 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.033	0.014	0.055	0.001	0.364	184
Total-P (mg/L)	0.10	0.08	0.09	0.01	0.59	184
NH_3-N (mg/L)	0.035	0.024	0.037	0.007	0.243	184
NO_2-N + NO_3-N (mg/L)	0.162	0.020	0.305	0.008	1.97	184
TKN (mg/L)	0.44	0.36	0.35	0.06	2.28	184
TSS (mg/L)	7	4	9	1	68	184
Water Temp. (°C)	17.0	17.6	6.8	2.1	29.7	184
Conductivity (µmhos/cm)	591	589	114	305	1070	184
DO (mg/L)	7.7	7.4	2.8	1.3	14.4	184
pH (standard units)	7.9	7.9	0.2	7.3	8.5	184
Fecal Coliform (colonies/100ml)	710	130	3000	12	20000	46
Escherichia coli (colonies/100ml)	710	110	3400	5	39000	152

Table A-4 Routine grab sample summary statistics for site GB020 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	4.40	4.07	2.75	0.69	7.60	6
Total-P (mg/L)	10.6	5.65	9.64	3.36	28.2	7
NH_3-N (mg/L)	0.577	0.304	0.610	0.079	1.59	5
NO_2-N + NO_3-N (mg/L)	2.943	0.932	3.847	0.240	9.87	7
TKN (mg/L)	41.3	6.69	68.2	3.04	187	7
TSS (mg/L)	456	150	704	2	1980	7
Water Temp. (°C)	13.3	10.7	8.2	4.1	23.6	7
Conductivity (µmhos/cm)	1010	437	1220	178	3270	7
DO (mg/L)	8.0	7.3	2.6	5.2	11.6	7
pH (standard units)	8.1	8.1	0.3	7.8	8.5	7
Fecal Coliform (colonies/100ml)	260000	260000	360000	9700	510000	2
Escherichia coli (colonies/100ml)	200000	130000	220000	7300	500000	6

Table A-5 Routine grab sample summary statistics for site GC025 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.113	0.044	0.150	0.003	0.466	12
Total-P (mg/L)	0.22	0.12	0.20	0.03	0.64	12
NH_3-N (mg/L)	0.045	0.050	0.010	0.022	0.050	12
NO_2-N + NO_3-N (mg/L)	0.029	0.025	0.013	0.020	0.061	12
TKN (mg/L)	0.39	0.25	0.36	0.10	1.15	12
TSS (mg/L)	3	2	3	2	10	12
Water Temp. (°C)	14.5	13.5	5.1	6.8	25.1	12
Conductivity (µmhos/cm)	930	1050	326	291	1290	12
DO (mg/L)	9.2	9.3	2.1	6.3	12.1	12
pH (standard units)	8.1	8.1	0.1	7.8	8.3	12
Fecal Coliform (colonies/100ml)	.	.	.	.	.	0
Escherichia coli (colonies/100ml)	150	84	180	8	580	12

Table A-6 Routine grab sample summary statistics for site GC045 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.070	0.012	0.132	0.001	0.889	94
Total-P (mg/L)	0.17	0.11	0.18	0.01	1.11	94
NH_3-N (mg/L)	0.064	0.049	0.080	0.010	0.586	94
NO_2-N + NO_3-N (mg/L)	4.46	2.31	5.49	0.020	22.2	94
TKN (mg/L)	0.91	0.78	0.61	0.10	2.31	94
TSS (mg/L)	18	8	22	2	112	93
Water Temp. (°C)	18.5	20.0	6.3	4.6	28.0	94
Conductivity (µmhos/cm)	738	730	256	306	1440	94
DO (mg/L)	7.6	7.4	2.1	3.5	13.5	94
pH (standard units)	7.9	7.9	0.2	7.1	8.4	94
Fecal Coliform (colonies/100ml)	500	160	1000	2	4500	21
Escherichia coli (colonies/100ml)	3400	160	27000	0	240000	82

Table A-7 Routine grab sample summary statistics for site GM060 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.080	0.020	0.150	0.002	1.030	113
Total-P (mg/L)	0.16	0.09	0.21	0.01	1.46	113
NH_3-N (mg/L)	0.046	0.021	0.100	0.007	0.917	113
NO_2-N + NO_3-N (mg/L)	0.105	0.020	0.267	0.008	2.16	113
TKN (mg/L)	0.51	0.42	0.45	0.06	2.78	113
TSS (mg/L)	12	2	51	1	544	113
Water Temp. (°C)	17.6	17.5	7.7	2.5	37.4	113
Conductivity (µmhos/cm)	888	820	315	160	1720	113
DO (mg/L)	9.8	9.9	2.0	5.2	15.1	113
pH (standard units)	8.1	8.1	0.2	7.5	8.8	113
Fecal Coliform (colonies/100ml)	790	35	4200	2	26000	38
Escherichia coli (colonies/100ml)	820	25	3600	0	25000	95

Table A-8 Routine grab sample summary statistics for site HY060 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.007	0.003	0.013	0.001	0.102	107
Total-P (mg/L)	0.07	0.05	0.06	0.01	0.48	107
NH_3-N (mg/L)	0.028	0.014	0.025	0.007	0.163	107
NO_2-N + NO_3-N (mg/L)	0.455	0.025	0.924	0.009	4.06	107
TKN (mg/L)	0.32	0.27	0.25	0.06	1.30	107
TSS (mg/L)	4	2	9	1	90	107
Water Temp. (°C)	18.6	20.3	6.5	5.6	28.0	107
Conductivity (µmhos/cm)	521	536	76	287	643	107
DO (mg/L)	8.2	8.0	2.2	3.6	14.8	107
pH (standard units)	7.8	7.8	0.2	7.3	8.2	107
Fecal Coliform (colonies/100ml)	140	66	260	5	1400	37
Escherichia coli (colonies/100ml)	100	46	170	2	1200	95

Table A-9 Routine grab sample summary statistics for site IC020 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.326	0.170	0.472	0.007	3.01	64
Total-P (mg/L)	0.56	0.32	0.73	0.03	4.16	64
NH_3-N (mg/L)	0.230	0.050	0.574	0.010	3.68	63
NO_2-N + NO_3-N (mg/L)	2.01	1.52	2.66	0.008	16.9	64
TKN (mg/L)	2.07	1.54	2.20	0.10	15.3	64
TSS (mg/L)	19	9	39	2	240	64
Water Temp. (°C)	18.7	19.0	6.8	6.2	31.3	64
Conductivity (µmhos/cm)	1250	1190	542	172	2800	64
DO (mg/L)	12.1	11.9	3.2	5.8	20.8	64
pH (standard units)	8.2	8.3	0.3	7.5	8.9	64
Fecal Coliform (colonies/100ml)	13000	780	51000	0	220000	18
Escherichia coli (colonies/100ml)	3800	360	17000	0	120000	50

Table A-10 Routine grab sample summary statistics for site LD040 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.518	0.388	0.433	0.008	2.47	58
Total-P (mg/L)	0.81	0.54	0.97	0.03	5.40	58
NH_3-N (mg/L)	0.191	0.058	0.459	0.010	2.52	56
NO_2-N + NO_3-N (mg/L)	3.00	1.48	3.66	0.015	14.4	58
TKN (mg/L)	2.86	1.41	6.35	0.10	36.6	58
TSS (mg/L)	21	9	29	1	127	58
Water Temp. (°C)	16.3	16.4	6.2	6.0	26.8	58
Conductivity (µmhos/cm)	1240	1290	493	127	2390	58
DO (mg/L)	8.6	8.5	2.9	2.7	15.8	58
pH (standard units)	7.9	7.9	0.2	7.5	8.3	58
Fecal Coliform (colonies/100ml)	6200	1400	9700	46	24000	9
Escherichia coli (colonies/100ml)	7500	460	18000	8	77000	53

Table A-11 Routine grab sample summary statistics for site LG060 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.084	0.031	0.166	0.003	1.39	84
Total-P (mg/L)	0.19	0.13	0.22	0.03	1.73	84
NH_3-N (mg/L)	0.077	0.050	0.112	0.008	0.895	84
NO_2-N + NO_3-N (mg/L)	0.442	0.186	0.621	0.009	2.48	84
TKN (mg/L)	1.09	0.85	1.10	0.10	8.85	84
TSS (mg/L)	20	8	28	2	171	84
Water Temp. (°C)	17.6	18.5	6.6	3.6	29.0	84
Conductivity (µmhos/cm)	673	666	234	171	1100	84
DO (mg/L)	9.3	8.8	2.5	4.7	15.2	84
pH (standard units)	8.1	8.1	0.2	7.7	8.6	84
Fecal Coliform (colonies/100ml)	4400	755	10000	70	40000	21
Escherichia coli (colonies/100ml)	5800	326	26000	30	200000	73

Table A-12 Routine grab sample summary statistics for site NF009 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.179	0.101	0.175	0.008	0.750	88
Total-P (mg/L)	0.36	0.28	0.28	0.03	1.63	88
NH_3-N (mg/L)	0.145	0.050	0.252	0.007	1.42	87
NO_2-N + NO_3-N (mg/L)	0.386	0.030	0.805	0.009	4.01	88
TKN (mg/L)	1.55	1.16	1.82	0.10	15.9	88
TSS (mg/L)	24	13	36	1	274	88
Water Temp. (°C)	14.9	15.3	6.5	2.6	26.8	88
Conductivity (µmhos/cm)	2060	2000	922	270	4290	88
DO (mg/L)	7.3	7.4	3.4	1.4	16.9	88
pH (standard units)	7.9	7.8	0.2	7.4	8.7	88
Fecal Coliform (colonies/100ml)	1300	210	2900	22	12000	21
Escherichia coli (colonies/100ml)	2800	690	11000	6	92000	80

Table A-13 Routine grab sample summary statistics for site NF020 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	1.06	0.981	0.806	0.156	4.08	31
Total-P (mg/L)	1.47	1.17	1.03	0.22	4.57	31
NH_3-N (mg/L)	0.267	0.105	0.372	0.010	1.69	32
NO_2-N + NO_3-N (mg/L)	0.847	0.368	1.18	0.020	5.28	32
TKN (mg/L)	3.26	2.59	2.02	1.28	9.74	32
TSS (mg/L)	33	17	41	2	192	32
Water Temp. (°C)	14.1	14.0	5.0	5.6	25.2	32
Conductivity (µmhos/cm)	2580	2220	1540	260	5400	32
DO (mg/L)	8.4	8.1	2.8	4.2	15.5	32
pH (standard units)	8.0	8.0	0.2	7.6	8.5	32
Fecal Coliform (colonies/100ml)	77000	13000	98000	170	190000	5
Escherichia coli (colonies/100ml)	13000	900	35000	73	140000	28

Table A-14 Routine grab sample summary statistics for site NF050 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.348	0.323	0.199	0.045	0.796	58
Total-P (mg/L)	0.55	0.54	0.31	0.07	1.76	58
NH_3-N (mg/L)	0.116	0.050	0.184	0.010	1.05	58
NO_2-N + NO_3-N (mg/L)	0.321	0.241	0.369	0.015	1.80	58
TKN (mg/L)	1.88	1.79	0.74	0.48	4.75	58
TSS (mg/L)	32	18	80	2	610	58
Water Temp. (°C)	17.3	17.5	6.4	5.9	26.9	58
Conductivity (µmhos/cm)	691	480	496	177	1890	58
DO (mg/L)	8.3	7.8	2.7	2.4	14.9	58
pH (standard units)	8.2	8.2	0.2	7.8	9.1	58
Fecal Coliform (colonies/100ml)	4400	1100	6300	0	17000	14
Escherichia coli (colonies/100ml)	8700	980	34000	0	240000	57

Table A-15 Routine grab sample summary statistics for site SC020 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.057	0.023	0.105	0.001	0.630	131
Total-P (mg/L)	0.14	0.12	0.14	0.01	0.84	131
NH_3-N (mg/L)	0.058	0.045	0.069	0.007	0.529	131
NO_2-N + NO_3-N (mg/L)	0.482	0.280	0.527	0.015	2.61	131
TKN (mg/L)	0.63	0.50	0.48	0.06	2.34	131
TSS (mg/L)	13	2	23	1	171	129
Water Temp. (°C)	15.7	16.3	6.8	2.6	27.2	131
Conductivity (µmhos/cm)	682	676	171	142	1380	131
DO (mg/L)	8.8	9.0	3.3	1.4	15.0	131
pH (standard units)	7.9	8.0	0.2	7.0	8.4	131
Fecal Coliform (colonies/100ml)	2200	450	5700	10	30000	33
Escherichia coli (colonies/100ml)	1500	240	6300	3	58000	110

Table A-16 Routine grab sample summary statistics for site SF085 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.220	0.191	0.181	0.005	1.22	153
Total-P (mg/L)	0.33	0.28	0.26	0.01	1.63	153
NH_3-N (mg/L)	0.052	0.036	0.065	0.007	0.541	153
NO_2-N + NO_3-N (mg/L)	0.310	0.183	0.364	0.008	2.23	153
TKN (mg/L)	0.89	0.74	0.67	0.10	3.87	153
TSS (mg/L)	12	4	22	1	160	153
Water Temp. (°C)	16.4	16.9	7.0	1.2	28.7	153
Conductivity (µmhos/cm)	718	708	316	158	1630	153
DO (mg/L)	8.7	8.5	3.1	2.7	16.6	153
pH (standard units)	8.1	8.1	0.2	7.6	9.0	153
Fecal Coliform (colonies/100ml)	570	160	1400	5	7400	45
Escherichia coli (colonies/100ml)	4200	210	24000	1	240000	126

Table A-17 Routine grab sample summary statistics for site SP020 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.005	0.003	0.007	0.001	0.048	119
Total-P (mg/L)	0.06	0.03	0.04	0.01	0.28	119
NH_3-N (mg/L)	0.022	0.010	0.018	0.007	0.096	119
NO_2-N + NO_3-N (mg/L)	0.071	0.020	0.180	0.008	1.18	119
TKN (mg/L)	0.24	0.18	0.19	0.02	1.00	119
TSS (mg/L)	5	2	7	1	43	119
Water Temp. (°C)	16.9	17.1	5.8	6.6	30.1	119
Conductivity (µmhos/cm)	504	514	56	317	597	119
DO (mg/L)	9.0	8.7	1.4	6.0	12.3	119
pH (standard units)	7.9	7.9	0.2	7.5	8.7	119
Fecal Coliform (colonies/100ml)	280	110	850	19	5200	37
Escherichia coli (colonies/100ml)	260	60	790	1	5000	96

Table A-18 Routine grab sample summary statistics for site WB050 (N = number of samples).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.003	0.003	0.000	0.003	0.003	6
Total-P (mg/L)	0.10	0.12	0.04	0.03	0.14	6
NH_3-N (mg/L)	0.045	0.050	0.011	0.022	0.050	6
NO_2-N + NO_3-N (mg/L)	0.060	0.025	0.088	0.020	0.239	6
TKN (mg/L)	0.28	0.10	0.44	0.10	1.19	6
TSS (mg/L)	2	2	0	2	2	6
Water Temp. (°C)	15.8	15.9	4.5	10.5	20.7	6
Conductivity (µmhos/cm)	520	523	26	484	555	6
DO (mg/L)	10.0	10.1	1.0	8.7	11.1	6
pH (standard units)	8.1	8.1	0.1	7.9	8.2	6
Fecal Coliform (colonies/100ml)	.	.	.	.	.	0
Escherichia coli (colonies/100ml)	150	70	230	43	610	6

Summary Statistics for Storm Events

All data analyses represent storms evaluated between January 1, 2001 and December 31, 2009. 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)	0.304	0.306	0.210	0.003	0.915	79
Total-P (mg/L)	0.67	0.67	0.44	0.04	1.74	79
NH_3-N (mg/L)	0.116	0.061	0.133	0.050	1.03	79
NO_2-N + NO_3-N (mg/L)	0.958	0.839	0.923	0.028	5.40	79
TKN (mg/L)	2.10	1.98	1.23	0.10	6.14	79
TSS (mg/L)	196	57	264	2	1125	79

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)	0.566	0.520	0.448	0.061	4.21	93
Total-P (mg/L)	0.98	0.92	0.65	0.25	5.74	93
NH_3-N (mg/L)	0.199	0.088	0.301	0.050	2.16	93
NO_2-N + NO_3-N (mg/L)	0.893	0.630	0.921	0.028	7.45	93
TKN (mg/L)	2.27	2.00	1.13	0.82	7.89	93
TSS (mg/L)	141	66	192	7	1177	93

Table B-3 Storm event summary statistics for site DC040 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.090	0.064	0.089	0.002	0.396	101
Total-P (mg/L)	0.38	0.24	0.47	0.04	3.59	101
NH_3-N (mg/L)	0.096	0.050	0.131	0.050	0.893	101
NO_2-N + NO_3-N (mg/L)	0.367	0.276	0.347	0.028	1.69	101
TKN (mg/L)	1.49	1.07	1.36	0.10	6.90	101
TSS (mg/L)	231	53	382	4	1930	101

Table B-4 Storm event summary statistics for site GB020 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	2.769	2.493	1.580	0.134	7.14	52
Total-P (mg/L)	3.93	3.56	1.91	0.40	9.24	52
NH_3-N (mg/L)	0.687	0.390	0.823	0.050	3.68	51
NO_2-N + NO_3-N (mg/L)	2.95	2.37	3.02	0.262	19.25	52
TKN (mg/L)	5.97	4.90	3.24	0.98	17.28	52
TSS (mg/L)	485	189	863	2	5598	52

Table B-5 Storm event summary statistics for site GC025 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.251	0.276	0.165	0.005	0.571	11
Total-P (mg/L)	0.53	0.55	0.28	0.03	0.96	11
NH_3-N (mg/L)	0.128	0.050	0.137	0.050	0.461	11
NO_2-N + NO_3-N (mg/L)	0.246	0.247	0.177	0.025	0.579	11
TKN (mg/L)	1.53	1.57	0.97	0.26	3.10	11
TSS (mg/L)	138	103	131	8	378	11

Table B-6 Storm event summary statistics for site GC045 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.140	0.113	0.119	0.002	0.496	70
Total-P (mg/L)	0.39	0.38	0.26	0.04	1.16	70
NH_3-N (mg/L)	0.093	0.059	0.095	0.010	0.421	70
NO_2-N + NO_3-N (mg/L)	3.29	1.40	4.53	0.076	19.0	70
TKN (mg/L)	1.76	1.66	1.00	0.10	5.06	70
TSS (mg/L)	174	69	258	2	1399	70

Table B-7 Storm event summary statistics for site GM060 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.296	0.267	0.269	0.002	0.864	73
Total-P (mg/L)	0.48	0.41	0.38	0.04	1.49	73
NH_3-N (mg/L)	0.100	0.050	0.164	0.050	1.35	73
NO_2-N + NO_3-N (mg/L)	0.304	0.255	0.314	0.028	1.53	73
TKN (mg/L)	1.25	1.21	0.81	0.10	4.61	73
TSS (mg/L)	85	42	115	4	576	73

Table B-8 Storm event summary statistics for site HY060 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.024	0.011	0.030	0.002	0.170	81
Total-P (mg/L)	0.14	0.10	0.12	0.04	0.74	81
NH_3-N (mg/L)	0.057	0.050	0.024	0.050	0.206	81
NO_2-N + NO_3-N (mg/L)	0.731	0.296	1.05	0.028	5.50	81
TKN (mg/L)	0.78	0.72	0.59	0.10	3.01	81
TSS (mg/L)	69	28	107	4	607	81

Table B-9 Storm event summary statistics for site IC020 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.586	0.551	0.413	0.021	1.91	92
Total-P (mg/L)	1.15	1.06	0.62	0.11	2.75	92
NH_3-N (mg/L)	0.259	0.108	0.478	0.050	4.14	92
NO_2-N + NO_3-N (mg/L)	1.28	1.05	1.04	0.028	4.54	92
TKN (mg/L)	3.39	3.12	1.71	0.72	11.5	92
TSS (mg/L)	338	188	372	26	1750	92

Table B-10 Storm event summary statistics for site LD040 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.563	0.568	0.274	0.032	1.25	71
Total-P (mg/L)	1.16	1.22	0.50	0.26	2.21	72
NH_3-N (mg/L)	0.379	0.148	0.692	0.016	3.93	71
NO_2-N + NO_3-N (mg/L)	1.78	1.17	2.24	0.028	13.7	72
TKN (mg/L)	3.83	3.42	1.92	0.72	9.81	72
TSS (mg/L)	350	180	395	4	2148	72

Table B-11 Storm event summary statistics for site LG060 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.186	0.132	0.174	0.004	0.737	49
Total-P (mg/L)	0.68	0.40	0.72	0.11	3.28	49
NH_3-N (mg/L)	0.159	0.081	0.165	0.010	0.762	49
NO_2-N + NO_3-N (mg/L)	0.563	0.400	0.481	0.028	2.82	49
TKN (mg/L)	2.89	1.93	2.73	0.10	13.2	49
TSS (mg/L)	293	104	456	2	2140	49

Table B-12 Storm event summary statistics for site NF009 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.333	0.326	0.182	0.002	1.24	81
Total-P (mg/L)	0.92	0.62	1.38	0.16	10.1	81
NH_3-N (mg/L)	0.239	0.117	0.357	0.050	2.64	81
NO_2-N + NO_3-N (mg/L)	0.762	0.499	0.968	0.028	5.94	81
TKN (mg/L)	2.86	2.03	3.20	0.36	24.1	81
TSS (mg/L)	528	130	1820	13	12300	81

Table B-13 Storm event summary statistics for site NF020 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.935	0.755	0.683	0.028	3.96	89
Total-P (mg/L)	2.05	1.62	1.51	0.45	8.40	89
NH_3-N (mg/L)	0.320	0.184	0.399	0.050	2.02	88
NO_2-N + NO_3-N (mg/L)	1.17	0.783	0.976	0.261	6.82	89
TKN (mg/L)	5.43	3.97	4.15	1.39	26.0	89
TSS (mg/L)	701	322	1639	2	14900	89

Table B-14 Storm event summary statistics for site NF050 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.461	0.425	0.197	0.123	1.30	76
Total-P (mg/L)	0.91	0.81	0.43	0.18	2.33	76
NH_3-N (mg/L)	0.158	0.111	0.137	0.050	0.746	76
NO_2-N + NO_3-N (mg/L)	0.501	0.435	0.375	0.051	2.13	76
TKN (mg/L)	2.51	2.04	1.37	0.66	8.24	76
TSS (mg/L)	222	94	369	2	2261	76

Table B-15 Storm event summary statistics for site SC020 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.167	0.118	0.170	0.003	0.862	98
Total-P (mg/L)	0.41	0.38	0.33	0.04	2.06	99
NH_3-N (mg/L)	0.145	0.050	0.396	0.050	3.88	99
NO_2-N + NO_3-N (mg/L)	0.485	0.402	0.399	0.025	2.20	99
TKN (mg/L)	1.52	1.33	1.03	0.10	7.27	99
TSS (mg/L)	140	66	176	4	851	99

Table B-16 Storm event summary statistics for site SF085 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.246	0.222	0.125	0.016	0.692	172
Total-P (mg/L)	0.50	0.41	0.35	0.05	2.90	172
NH_3-N (mg/L)	0.113	0.053	0.178	0.050	1.86	172
NO_2-N + NO_3-N (mg/L)	0.384	0.321	0.271	0.028	1.53	172
TKN (mg/L)	1.45	1.24	1.15	0.10	9.51	172
TSS (mg/L)	122	41	217	4	1360	172

Table B-17 Storm event summary statistics for site SP020 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.025	0.007	0.055	0.003	0.449	87
Total-P (mg/L)	0.15	0.10	0.15	0.04	1.00	87
NH_3-N (mg/L)	0.056	0.050	0.023	0.050	0.203	87
NO_2-N + NO_3-N (mg/L)	0.087	0.042	0.093	0.028	0.531	87
TKN (mg/L)	0.71	0.53	0.59	0.10	2.84	87
TSS (mg/L)	103	26	207	4	1490	87

Table B-18 Storm event summary statistics for site WB050 (N = number of events).

Constituent	Mean	Median	Std Dev.	Minimum	Maximum	N
PO_4-P (mg/L)	0.049	0.043	0.039	0.003	0.120	10
Total-P (mg/L)	0.24	0.22	0.16	0.03	0.43	10
NH_3-N (mg/L)	0.057	0.050	0.022	0.050	0.118	10
NO_2-N + NO_3-N (mg/L)	0.160	0.126	0.139	0.025	0.461	10
TKN (mg/L)	1.13	1.17	0.78	0.10	2.15	10
TSS (mg/L)	146	112	168	2	545	10

APPENDIX C

Record of Average Daily Flow for Each Stream Site

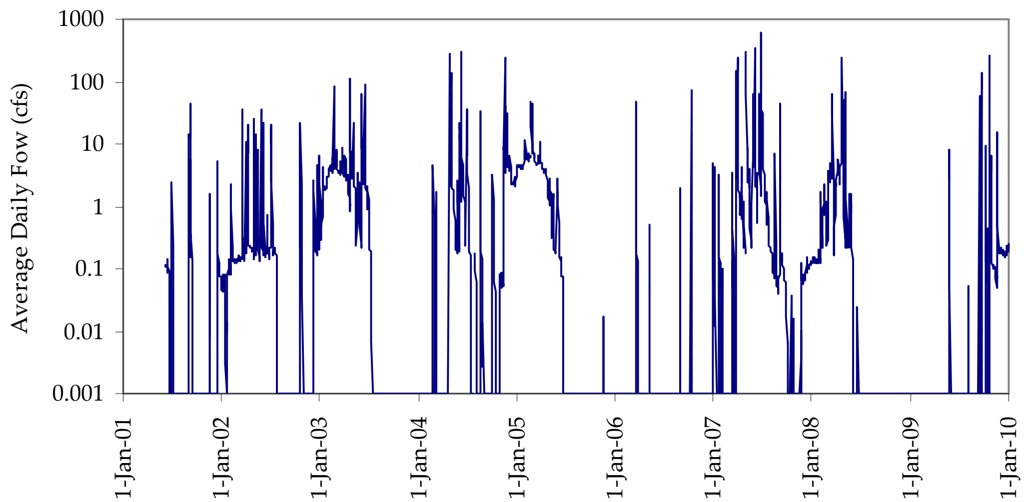

Figure C-1 Average daily flow at AL020 for July 1, 2001 through December 31, 2009. Missing daily values exist for July 26-29, 2004; May 6-7, 2006; and April 30-May 1, 2007.

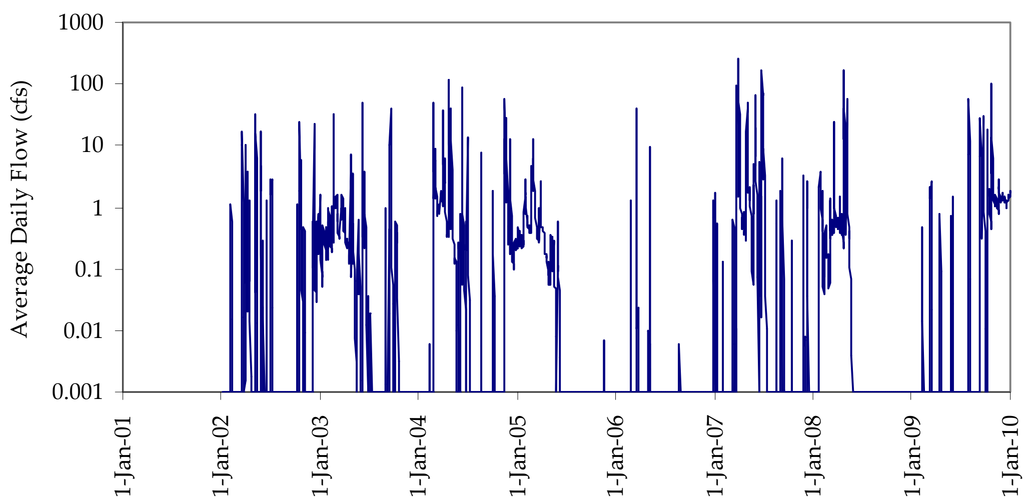

Figure C-2 Average daily flow at DB035 for January 4, 2002 through December 31, 2009.

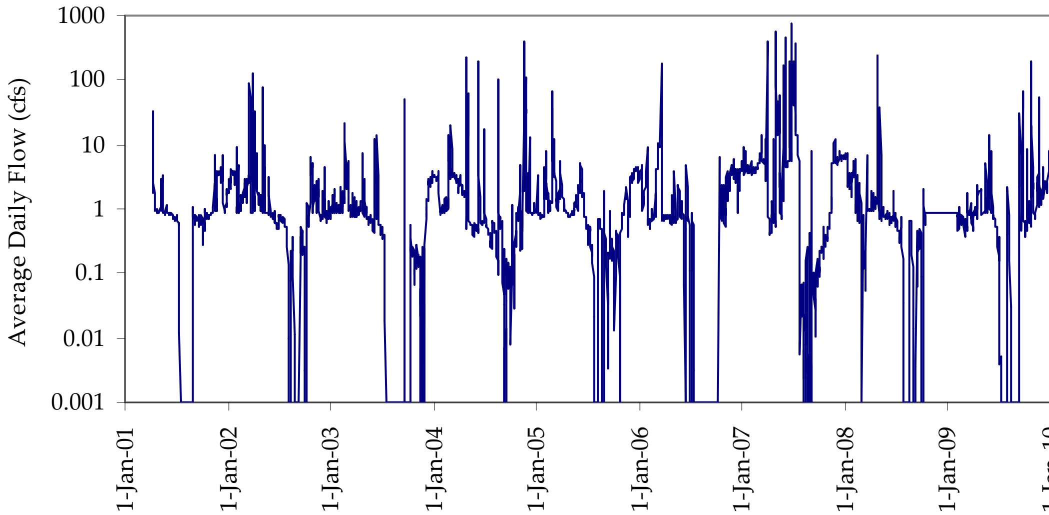

Figure C-3 Average daily flow at DC040 for April 10, 2001 through December 31, 2009. Daily values for October 15, 2008 through February 1, 2009 set to a constant of 0.9 cfs. A low flow was occurring but a beaver dam below the site elevated stream levels in relation to normal flows. No storm events occurred during this time.

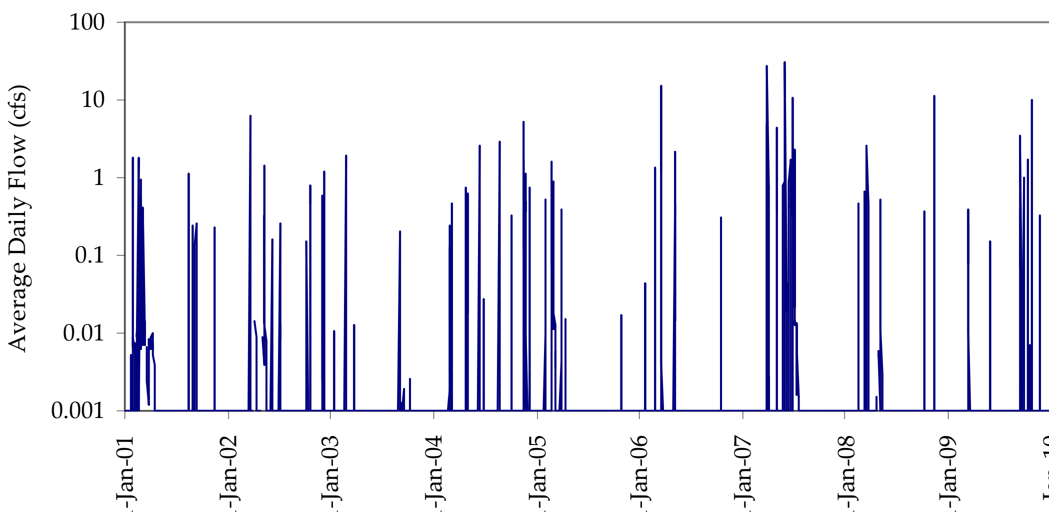

Figure C-4 Average daily flow at GB020 for January 1, 2001 through December 31, 2009. Missing daily values exist for March 11-18, 2001; March 30-April 8, 2002; April 26-May 6, 2002, and April 18-28, 2008.

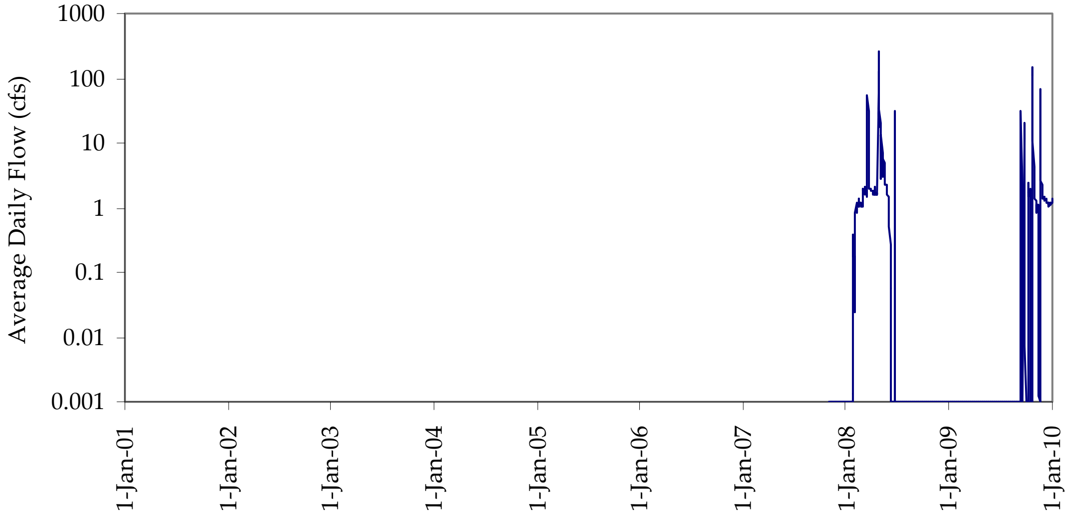

Figure C-5 Average daily flow at GC025 for November 1, 2007 through December 31, 2009.

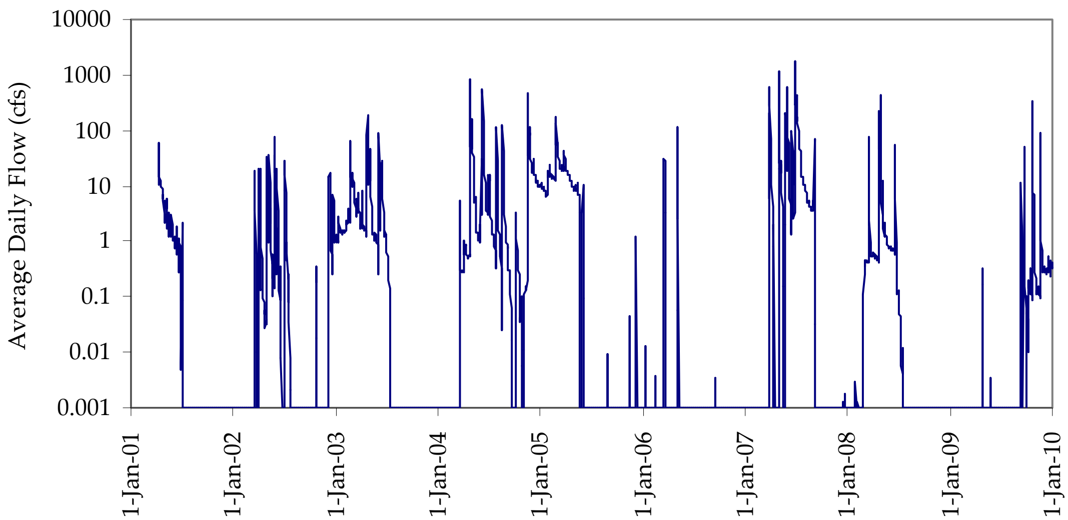

Figure C-6 Average daily flow at GC045 for April 9, 2001 through December 31, 2009.

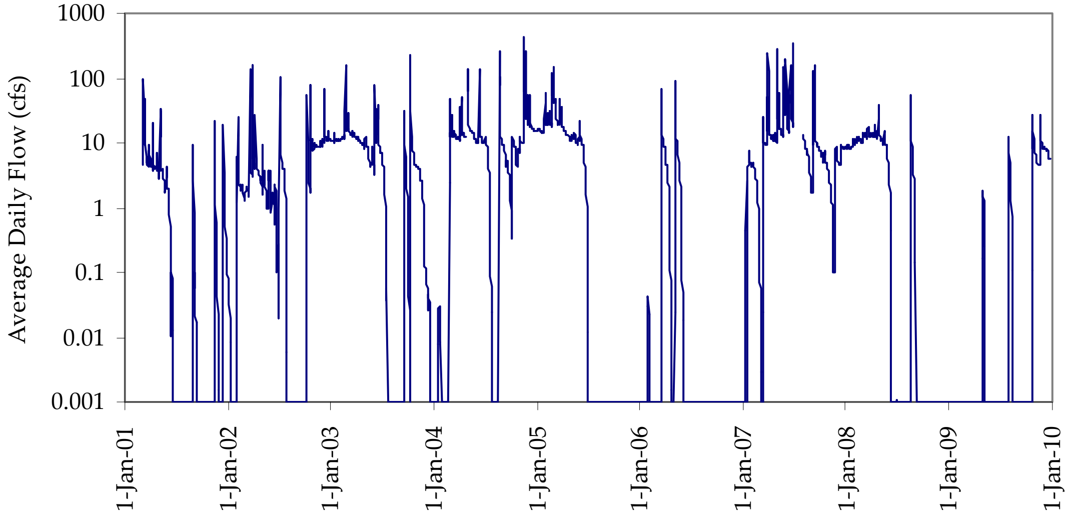

Figure C-7 Average daily flow at GM060 for March 7, 2001 through December 31, 2009. Missing daily values exist for April 24-30, 2004 and June 27-August 2, 2007.

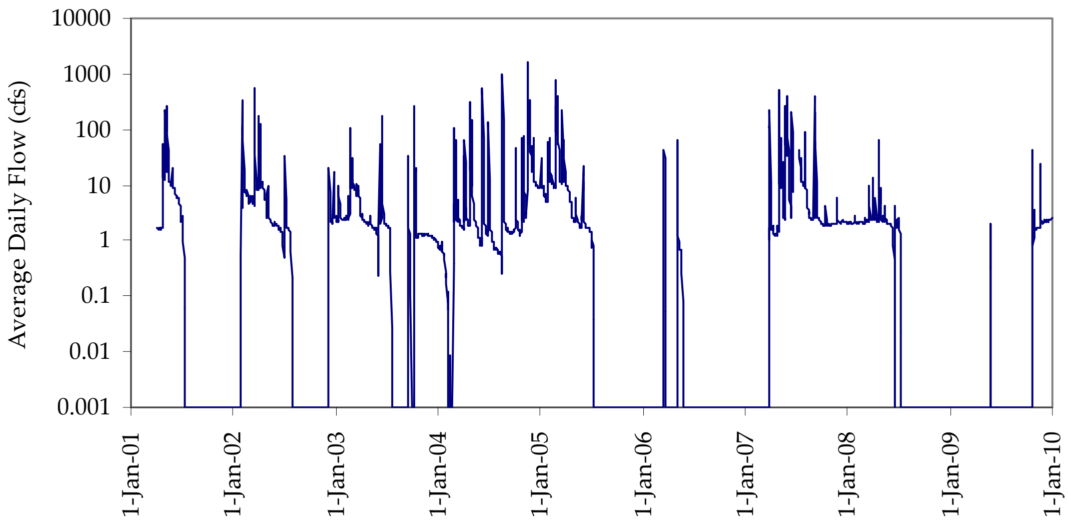

Figure C-8 Average daily flow at HY060 for April 5, 2001 through December 31, 2009. Missing daily values exist for June 25-July 13, 2007.

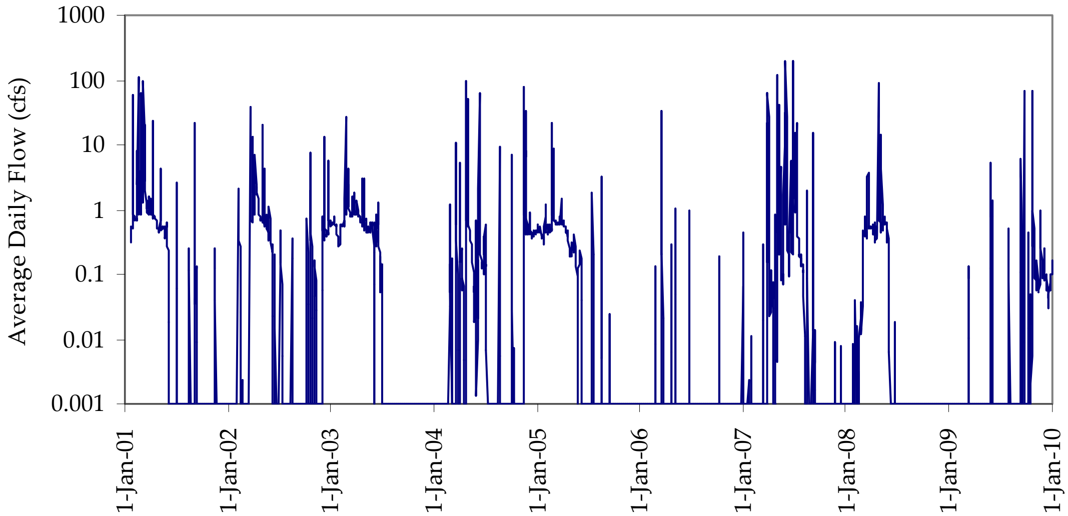

Figure C-9 Average daily flow at IC020 for January 24, 2001 through December 31, 2009. Missing daily values exist for November 14-15, 2004.

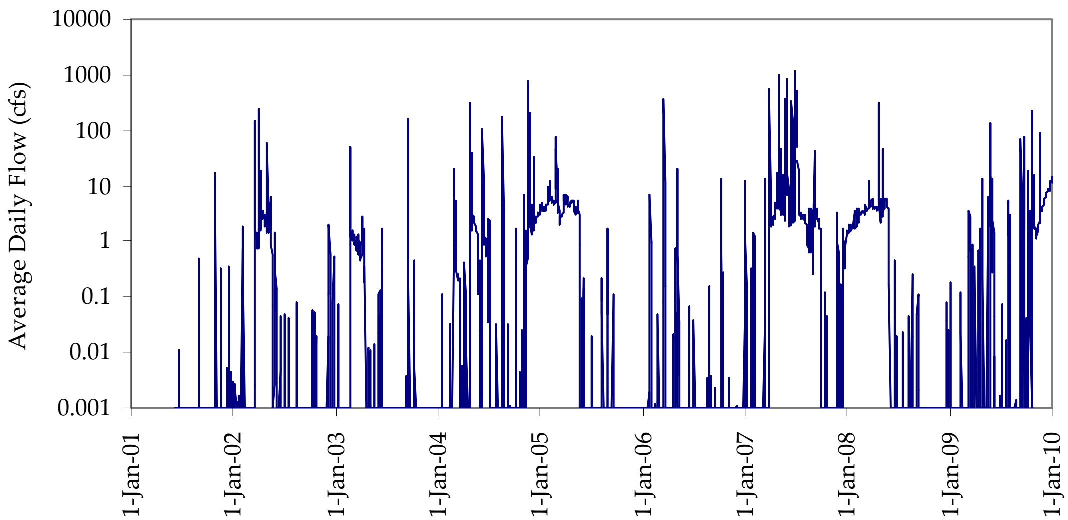

Figure C-10 Average daily flow at LD040 for June 6, 2001 through December 31, 2009. Missing daily values exist for July 6-9, 2007.

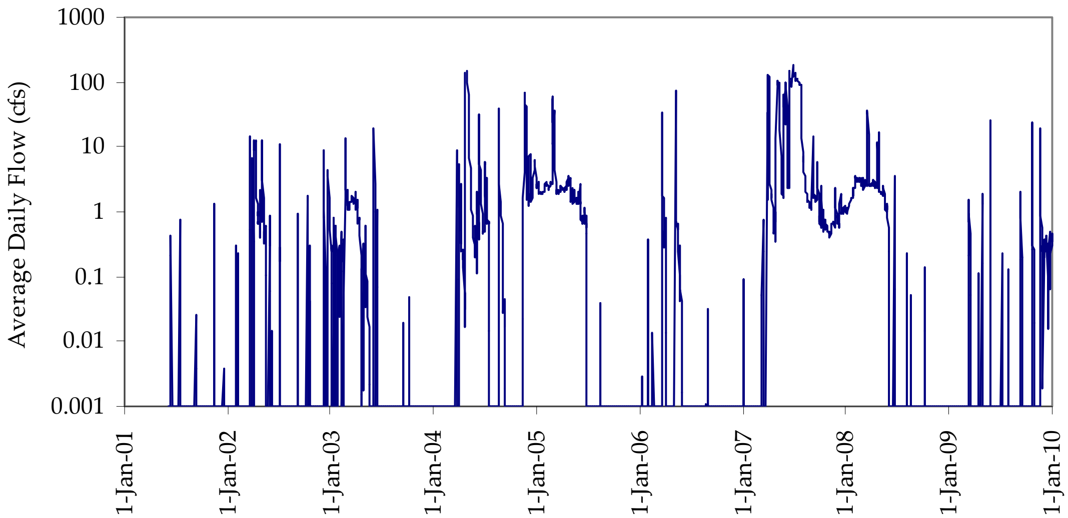

Figure C-11 Average daily flow at LG060 for June 6, 2001 through December 31, 2009. Missing daily value exist for April 24-29, 2004.

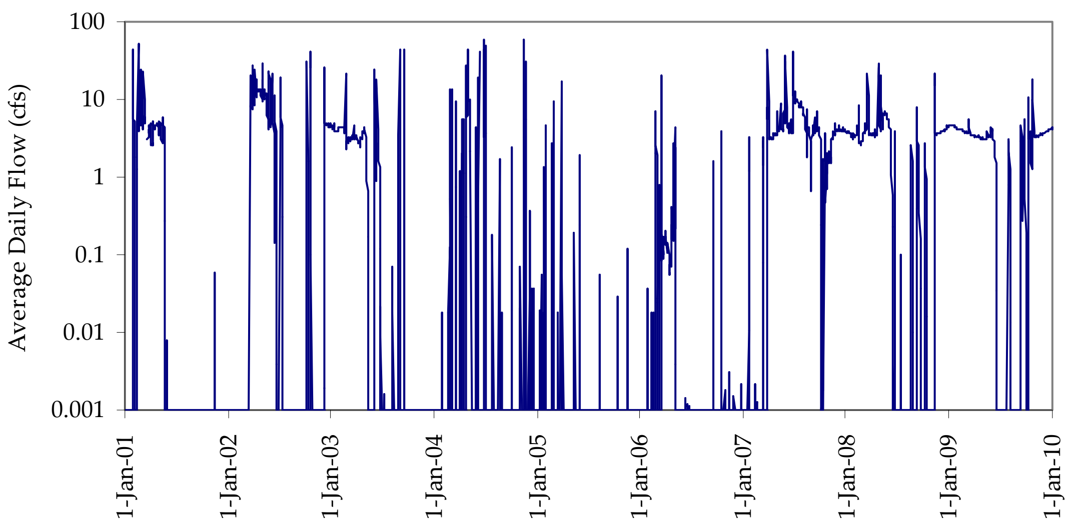

Figure C-12 Average daily flow at NF009 for January 1, 2001 through December 31, 2009. Missing daily values exist for March 13-22, 2001; August 31-September 1, 2003; June 9-15, 2004; and October 4-5, 2004.

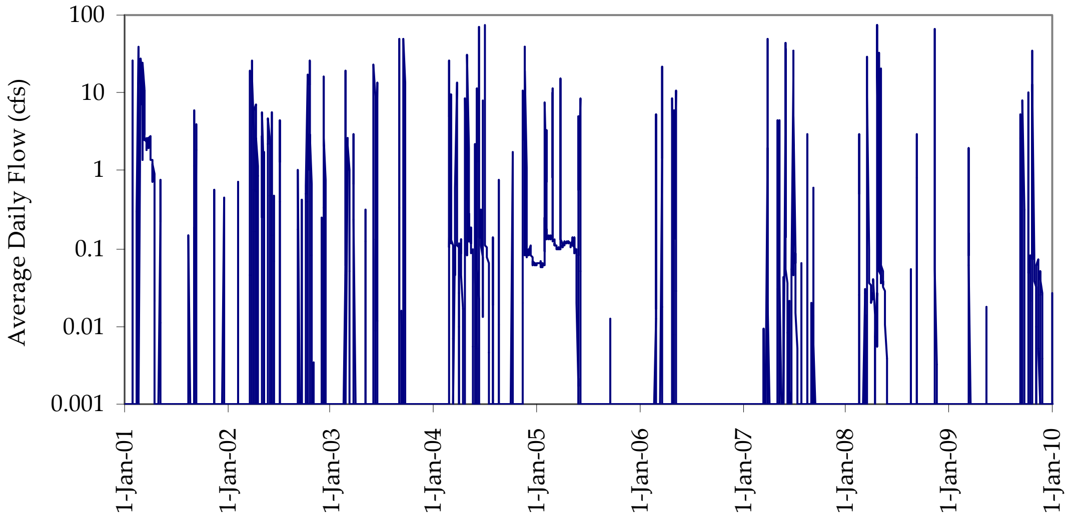

Figure C-13 Average daily flow at NF020 for January 1, 2001 through December 31, 2009. Missing daily values exist for June 25-29, 2004.

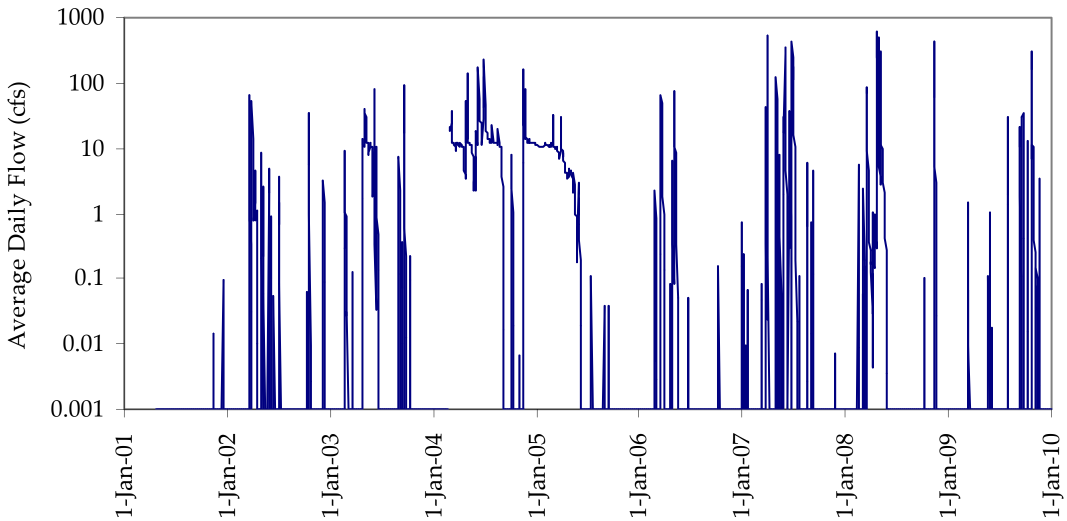

Figure C-14 Average daily flow at NF050 for April 26, 2001 through December 31, 2009. Missing daily values exist for February 23-March 2, 2004 and March 26-27, 2005.

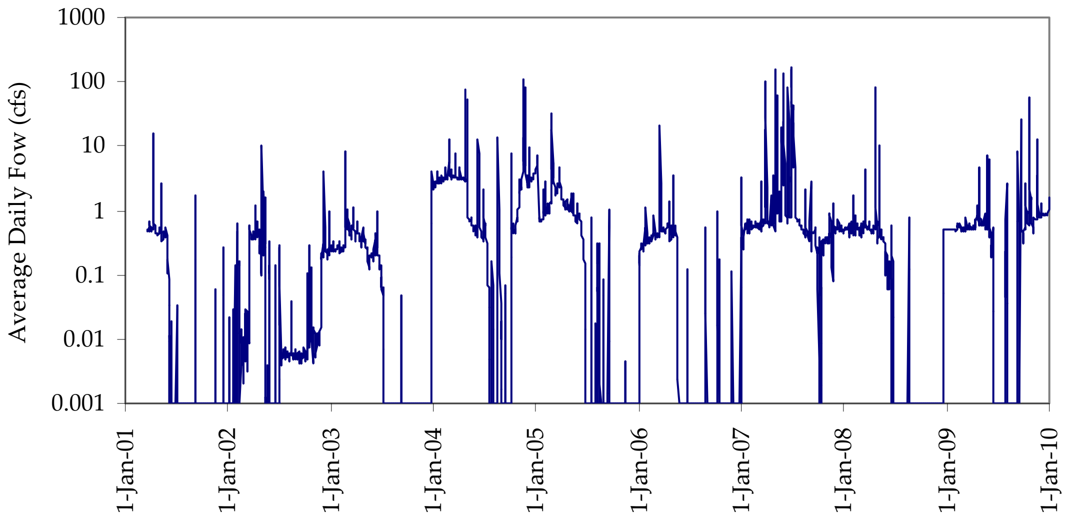

Figure C-15 Average daily flow at SC020 for March 20, 2001 through December 31, 2009. Missing daily values exist for April 24-30, 2004. Daily estimates for December 21, 2008 through February 1, 2009 were set to a constant of 0.5 cfs. A low flow was occurring but a beaver dam below the site elevated stream levels in relation to normal flows. No storm events occurred during this time.

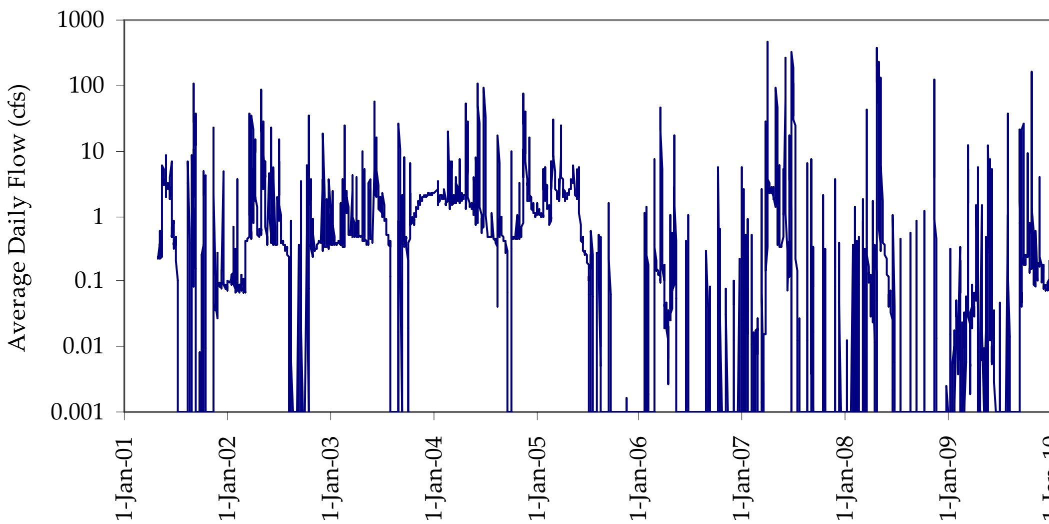

Figure C-16 Average daily flow at SF085 for May 1, 2001 through December 31, 2009. Missing daily values exist for February 23, 2005 and February 10-11, 2009.

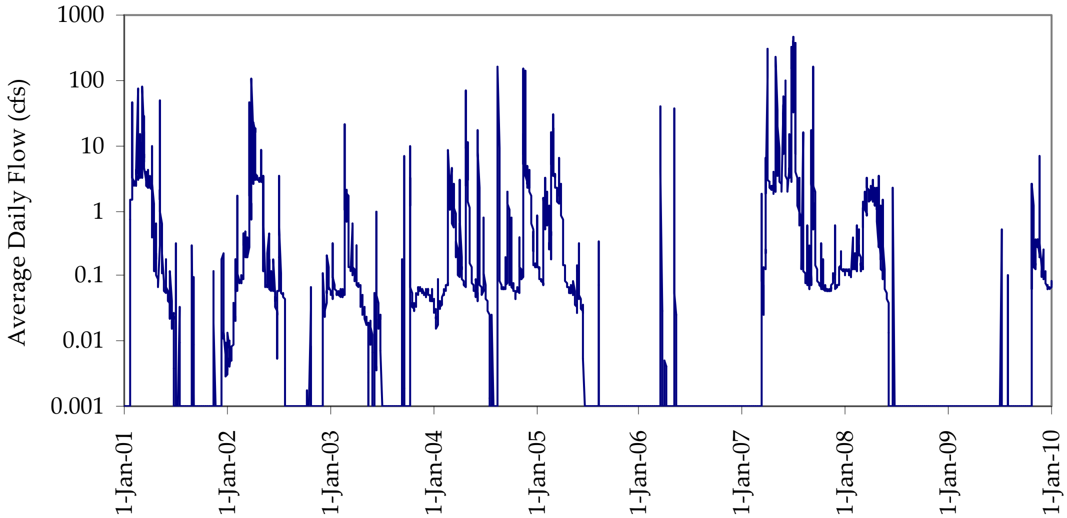

Figure C-17 Average daily flow at SP020 for January 3, 2001 through December 31, 2009. Missing daily values exist for April 24, 2004.

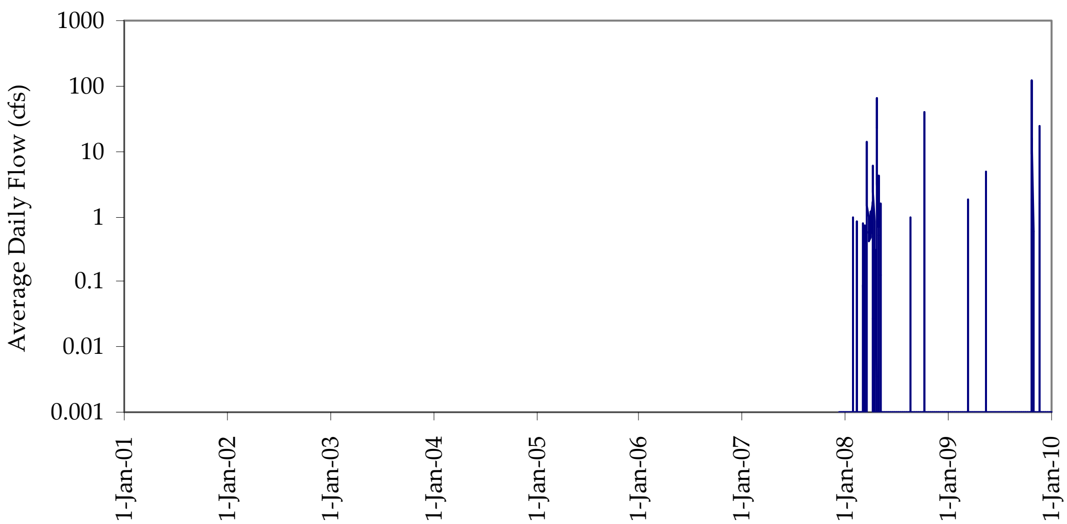

Figure C-18 Average daily flow at WB050 for December 10, 2007 through December 31, 2009.