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# Extending TMDL Efforts in the North Bosque River Watershed: Data Evaluation through 2007

## Final Project Report

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TSSWCB 01-017

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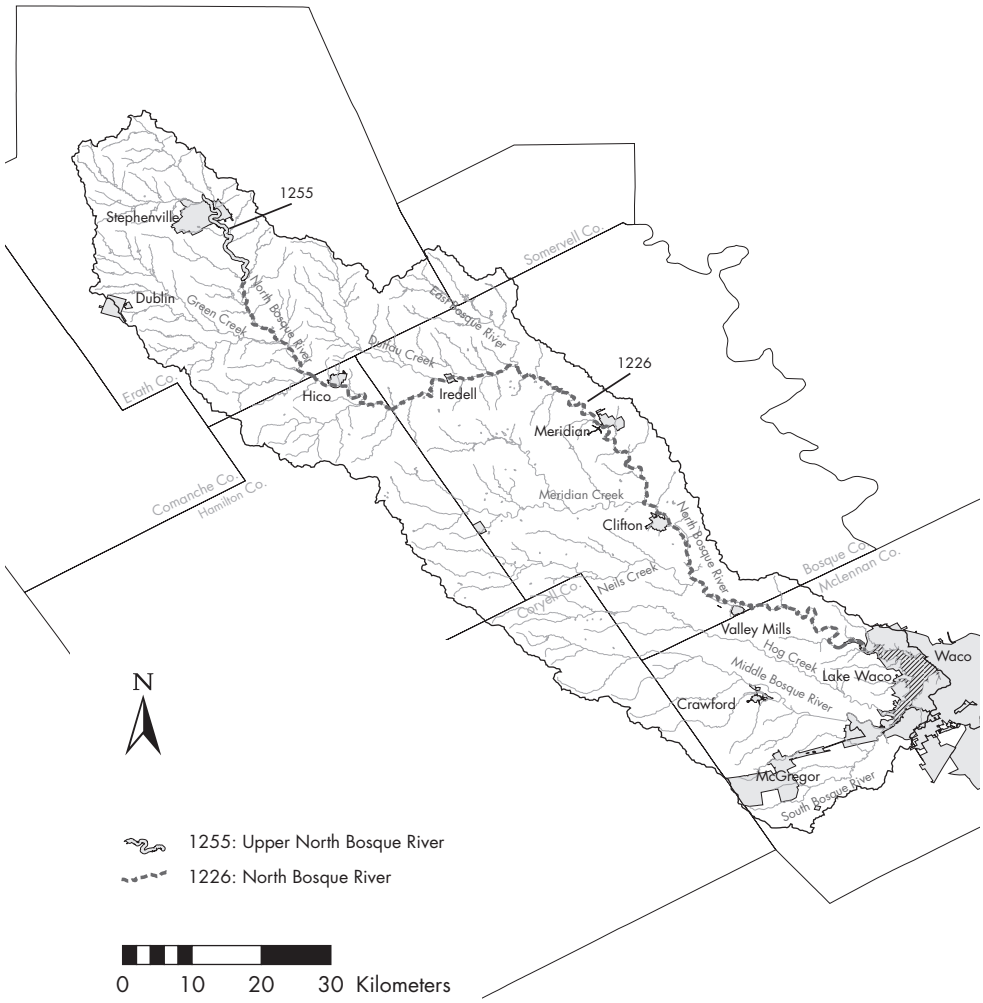
# CHAPTER 1

# Introduction

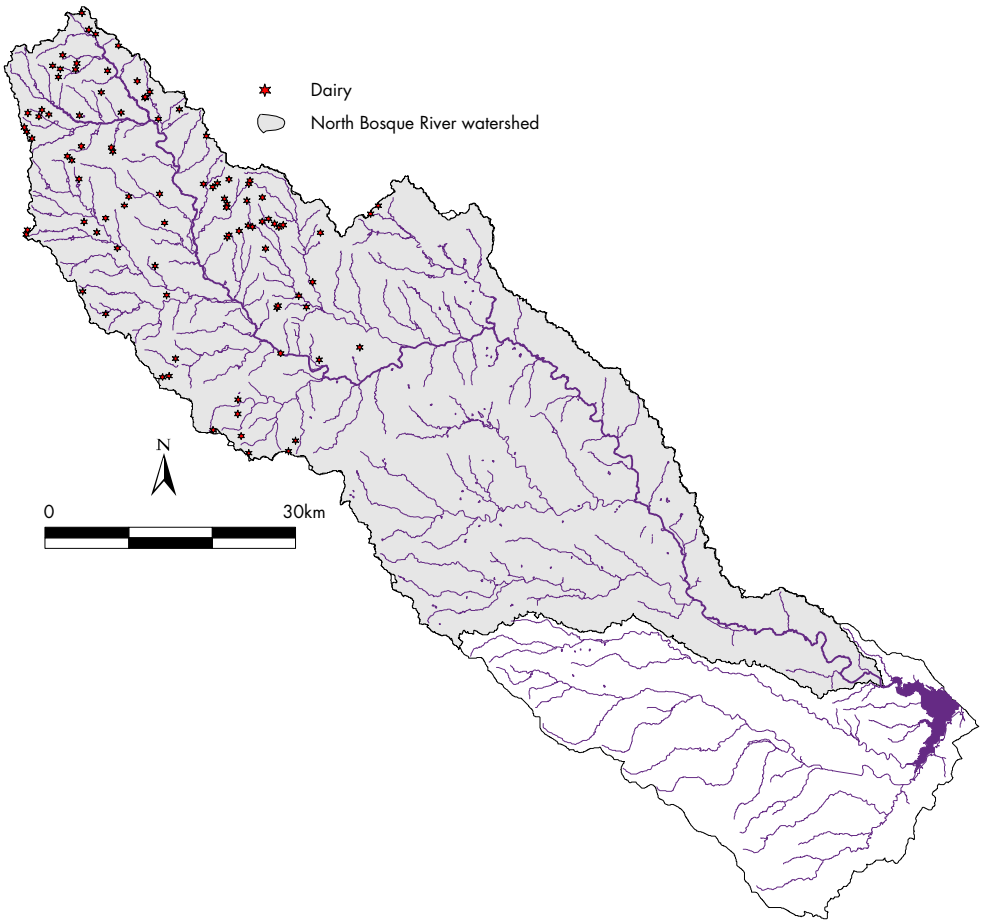
The basis for this project is to provide assessment activities in the North Bosque River watershed to support the Texas State Soil and Water Conservation Board (TSSWCB) and local Soil and Water Conservation Districts (SWCDs) in efforts to reduce agricultural nonpoint source (NPS) pollution loadings. The North Bosque River is located within the Brazos River Basin in north-central Texas (Figure 1), and extends from Erath County, where its headwaters initiate just north of the city of Stephenville, to Waco, Texas where the river enters into Lake Waco.

**Figure 1** Classified stream segments along the North Bosque River.



Statewide attention has focused on the North Bosque River watershed largely as the result of the prominence of the dairy industry in the northern portion of the watershed (Figure 2). The headwaters of the North Bosque River are located in Erath County, the number one milk producing county in Texas (USDA-AMS, 2008). The 1996 State of Texas Water Quality Inventory indicated that nonpoint source loadings associated with elevated nutrient and fecal coliform levels were the most serious threat to meeting designated uses within Segments 1226 and 1225 (TNRCC, 1996). In 1998, Segments 1226 and 1255 were included in the Clean Water Act Section 303(d) list for Texas as impaired water bodies under narrative water quality criteria related to nutrients and aquatic plant growth with concentrated animal feeding operations identified as the major nonpoint source of nutrients (TNRCC & TSSWCB, 1999).

**Figure 2** Location of dairies within the North Bosque River watershed. Represents active dairies as of October 2001.




In February 2001, the Texas Commission on Environmental Quality (TCEQ) adopted a total maximum daily load (TMDL) for soluble reactive phosphorus in Segments 1226 and 1255 that was approved by EPA in December 2001. This TMDL requires about a 50 percent reduction in loading and concentration of soluble reactive

phosphorus, depending on the location along the river (TNRCC, 2001). Soluble reactive phosphorus was identified as the nutrient limiting algal growth in the North Bosque River, and, thus, a reduction in soluble reactive phosphorus should reduce algal abundance in the North Bosque River. Although bacteria were also listed as a concern with regard to supporting the use of contact recreation along the North Bosque River, the TMDL process did not directly consider bacteria. Many of the control practices for phosphorus outlined in the Implementation Plan should also help reduce bacterial loadings to the North Bosque River.

The 2006 Texas Water Quality Inventory assessment prepared by the TCEQ pursuant to the Clean Water Act Section 305(b) still indicates impairments associated with bacteria and concerns associated with nutrient enrichment and algal growth on stream segments in the North Bosque River watershed (Table 1). Concerns regarding aquatic life use and nutrient enrichment are listed for both Segments 1226 and 1255, while impairments with regard to contact recreation are listed for Segment 1255.

**Table 1** Summary of TCEQ assessment of use impairments and concerns for 2006. 2006 Texas Water Quality Inventory (TCEQ, 2007a)

| Assessment | Segment 1226 - North Bosque River | Segment 1255 - Upper North Bosque River |
|---|---|---|
| Not Supporting | General use - nutrient enrichment | Contact recreation - bacteria; General use - nutrient enrichment |
| Description of Impairment | Excessive algal growth | *E. coli* exceeding single sample and geometric criteria and excessive algal growth |
| Concern | General use - nutrients; Aquatic life use - dissolved oxygen | General use - nutrients; Aquatic life use - dissolved oxygen |
| Description of Concern | Elevated chlorophyll-α and orthophosphorus and depressed dissolved oxygen (24-hr average and minimum) concentrations | Elevated ammonia, nitrate, orthophosphorus, total phosphorus, and chlorophyll-α and depressed dissolved oxygen (grab) concentrations |

As part of the Implementation Plan for the North Bosque River TMDLs, a microwatershed approach was proposed to target water quality monitoring and agricultural producer assistance to help reduce phosphorus loadings to the North Bosque River. This project represents a continuation of projects initiated as part of the Implementation Plan.[1] Microwatersheds, as defined in this report, are small watersheds that do not isolate any one landowner, but represent a small enough area to allow targeting of producers who may need assistance with the development of water quality management plans (WQMPs) or comprehensive nutrient management plans (CNMPs). As indicated in the Implementation Plan, "Monitoring microwatersheds will enable more precise identification of areas with waste management problems or inadequacies and better support efforts to improve management."

Within the TMDL, runoff from dairy waste application fields was identified as the most controllable nonpoint source contributing soluble reactive phosphorus (SRP) to the North Bosque River. While dairy producers and cow numbers can fluctuate

[1] TSSWCB Projects #01-13 and #01-14, Technical and Financial Assistance to Dairy Producers and Landowners of the North Bosque River Watershed within the Cross-Timbers and Upper Leon Soil and Water Conservation Districts.

substantially between and within years, in 2001 about 93 producers and 45,000 total head were estimated in the North Bosque watershed. This number has decreased with more recent estimates indicating about 65 producers and 40,000 total head in 2007.

As the lead agency for the State of Texas for the abatement of agricultural NPS pollution, the TSSWCB works closely with local SWCDs to reduce NPS pollution. The TSSWCB addresses the prevention or abatement of NPS pollution from various agricultural activities through the WQMP Program. A certified WQMP is a site-specific plan that includes appropriate land-treatment practices, production practices, technologies and combinations thereof, and an implementation schedule. This program is administered by the TSSWCB and provides agricultural producers in priority areas, such as the North Bosque River watershed, an opportunity to comply with state water quality laws through traditional voluntary incentive-based programs.

The TSSWCB oversees and is responsible for the cost-share component of the WQMP program. The local SWCDs are required to provide or arrange for technical assistance to applicants to implement best management practices (BMPs) through certified WQMPs. In many of the SWCDs in Texas, the Natural Resources Conservation Service (NRCS) also provides technical assistance in the development of WQMPs. The water quality assessment reported herein is designed to help target and support the need for WQMPs focusing on phosphorus reduction to help meet water quality goals of the North Bosque River TMDL.

Although direct monitoring under this project did not begin until April 2006, this project represents a continuation of monitoring funded through a number of different projects. Historical data from these other projects were used to help assess the impact of TMDL implementation efforts on stream water quality. One specific effort that was evaluated focuses on the removal of dairy-generated manure from the watershed. In late 2000, the TSSWCB and TCEQ established complementary programs that support the composting and export of dairy manure from the North Bosque River watershed. The TSSWCB Dairy Manure Export Support (DMES) program provides financial incentives to commercial manure haulers for the transport of raw manure from dairies to commercial composting facilities (TSSWCB, 2007). The TCEQ Composted Manure Incentive Project (CMIP) provides oversight of commercial compost facilities and rebates to Texas State agencies that use the manure compost (TCEQ, 2007c).

Within this report, routine grab and storm samples collected post-TMDL implementation were assessed to help target areas for focusing efforts by the TSSWCB and SWCDs for NPS management practices and concentrations of bacteria samples were evaluated in comparison to flow. Short-term trend analysis for data collected between 2001 and 2006 was conducted to determine changes in water quality during the post-TMDL implementation period. To evaluate a longer timeframe, a comparison of pre-implementation versus post-implementation effects with regard to manure haul-off associated with the composting program is presented using a “before” and “after” approach. “Before” data represent data collected prior to November 2000 when the composting program began, while “after” data including data from November 2000 through December 2006.

# CHAPTER 2

# Site Information

## Location and Sampling History

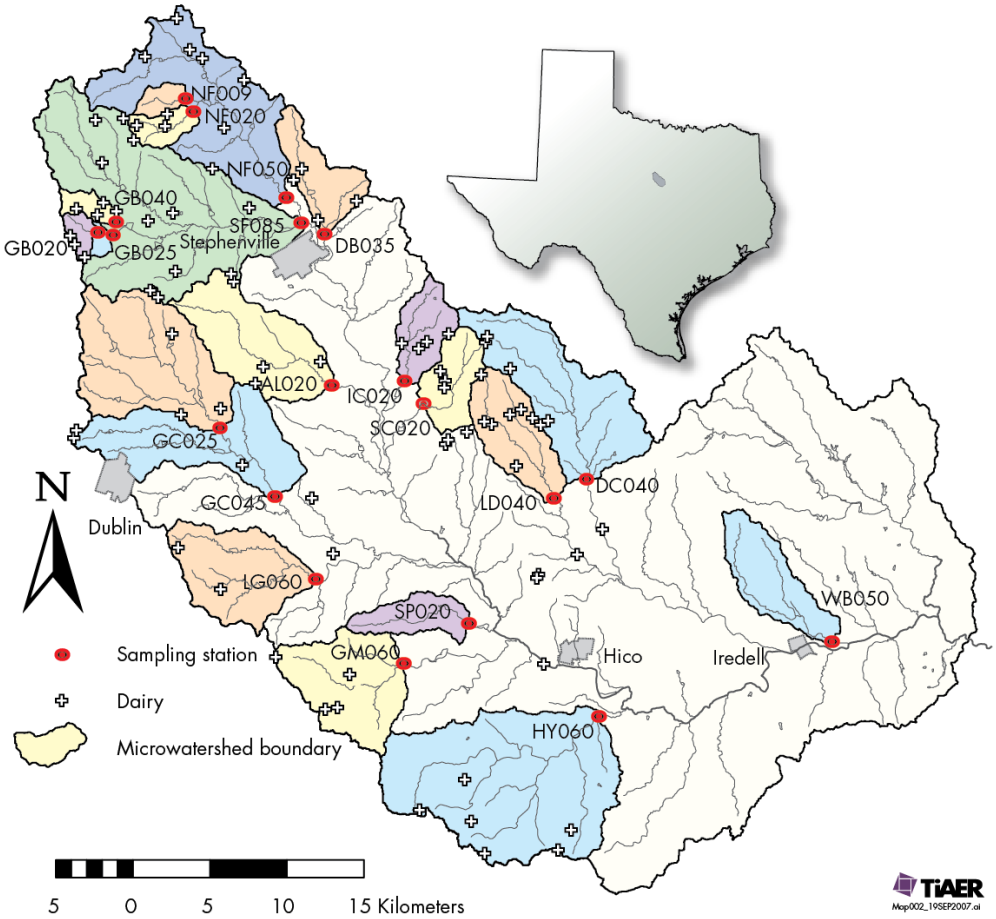
Twenty sampling sites were associated with the project (Figure 3), although data from only 18 sites are presented in this report. Data from sites GC025 and WB050 were not presented, because these two sites were installed late in the project and had very limited data (Table 2). Sites GC025 on Green Creek and WB050 on Walker Branch were not installed until December 2007. Sites GC025 and WB050 were installed to replace sites GB025 and GB040 on Goose Creek, which were removed in May 2007 at landowner request. Although only limited data could be collected at sites GC025 and WB050 during the project, these sites were initiated as part of the project in anticipation of continued monitoring under future projects in collaboration with the TSSWCB.

**Table 2** 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 | 05-Sep-01 |
| DB035 | 17603 | Dry Branch near FM 8 | 02-Apr-02 | 05-Feb-02 |
| DC040 | 17607 | Duffau Creek at FM 2481 | 16-Apr-01 | 07-May-01 |
| GB020 | 17214 | Unnamed tributary to Goose Branch between CR 541 and CR 297 | 11-May-95 | 05-May-95 |
| GB025 | 17213 | Unnamed tributary to Goose Branch near end of CR 297 | 12-Feb-97 | 19-May-97 |
| GB040 | 17215 | Goose Branch downstream of FM 8 | 12-Feb-97 | 06-Feb-97 |
| GC025 | TBA[a] | Green Creek downstream of FM 847 | 28-Jan-08 | 25-Jan-08 |
| GC045 | 17609 | Green Creek upstream of SH 6 | 16-Apr-01 | 26-May01 |
| GM060 | 17610 | Gilmore Creek at bend of CR 293 | 05-Feb-01 | 31-Aug-01 |
| HY060 | 17611 | Honey Creek at FM 1602 | 16-Apr-01 | 04-May-01 |
| IC020 | 17235 | Indian Creek downstream of US 281 | 08-Jun-94 | 18-Oct-93 [b] |
| 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 [c] |
| 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 | 04-Apr-91 [d] | 07-Jun-91 [d] |
| SC020 | 17240 | Sims Creek upstream of US 281 | 21-Sep-94 | 17-Jan-95 [b] |
| SF085 | 17602 | South Fork of North Bosque River at SH 108 | 30-Apr-01 | 26-May-01 |
| SP020 | 17242 | Spring Creek at CR 271 | 08-Jun-94 | 20-Oct-93 [b] |
| WB050 | TBA | Walker Branch at FM 927 | 28-Jan-08 | 26-Jan-08 |

a. TBA indicates to be assigned.
b. Storm sampling suspended 03-Mar-98 to 03-May-2001 at IC020 and SP020 and 03-Mar-98 to 12-May-2001 at SC020.
c. Automated sampler at NF009 was offline from 25-Mar-98 through 12-Jun-98.
d. Storm sampling at NF050 suspended from 09-Feb-97 to 04-May-01 and grab sampling suspended 06-May-97 through April 2001. In April 2001, grab sampling was reinitiated at NF050, but no samples were collected until April 2002 due to dry conditions.

**Figure 3** Location of sampling sites showing delineation of microwatersheds.




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.

# 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 (Figure 2). 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 GB025 and NF020, to allow comparison between different land uses (Table 3). The most recent land-use information available was based on classification of satellite imagery from 2001 through 2003 conducted by the Spatial Sciences Laboratory of the Texas Agricultural Experiment Station (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 waste application fields (WAFs) was based on detailed information obtained in 2000 from TCEQ records that was updated in the fall of 2007. The updated information on WAFs includes milking and non-milking operations, although milking operations represent over 80 percent of the 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 3** Updated 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[a] (%) | Urban or Impervious Surfaces (%) | Other (%) | Total Area (Hectares) | Estimated Cow Density (cows/ha)[b] |
|---|---|---|---|---|---|---|---|---|
| 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 |
| GB025 | 18.5 | 17.6 | 5.3 | 54.3 | 3.2 | 1.2 | 660 | 4.44 |
| GB040 | 10.0 | 31.8 | 21.0 | 31.1 | 5.2 | 1.0 | 540 | 3.18 |
| 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[c] | 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 |

a. Animal waste application fields represent estimates for milking and non-milking operations.
b. Cow numbers represent estimated values for 2007 based primarily on TCEQ inspection information for milking and non-milking animal feeding operations. For non-permitted operations without inspected values, head count was estimated as 70 percent of the maximum or 140 for dairy operations (maximum 199) and 210 head for non-dairy operations (maximum 299).
c. About 8 hectares (20 acres) or about 1 percent of the drainage area above site NF020 is permitted for septic disposal.

For previous reports associated with this project (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.

For comparison, the earlier land-use estimates are provided in Table 4 for all but sites GB025 and WB050, the two newest sites. All sites decreased in the percent of land area associated with wood and range and generally increased in the percent of land associated with improved pasture. The drainage area above site GB040 was an exception with a decrease in the percent pasture that was primarily offset by an increase in the percent cropland. The percent of land area associated with WAFs had only minor changes except for above NF020, which showed a decrease of about 11 percent. Of note, the historical land-use information for WAFs focused on just dairy waste application fields (Table 4), while more recent values include estimates for all animal feeding operations (Table 3). All sites showed increases in the categories of urban and other land uses; however, theses increases represented a relatively small percentage of the total drainage area for each site.

**Table 4** Historical land use and drainage information for sampling sites.
Land-use information based on classification of satellite imagery from 1992 through 1996 updated in 1998 based on ground-truthing. Information on animal waste application fields represents values as of May 2000. Estimated cow numbers represent values as of fall 2000 based on TCEQ records.

| Site | Wood & Range (%) | Pasture (%) | Cropland (%) | Dairy Waste App. Fields[a] (%) | Urban (%) | Other (%) | Total Area (Hectares) | Estimated Milking Cow Density (cows/ha)[b] |
|---|---|---|---|---|---|---|---|---|
| AL020 | 57.6 | 23.0 | 7.4 | 11.4 | 0.7 | 0.0 | 4,720 | 0.59 |
| DB035 | 46.2 | 24.1 | 12.8 | 14.0 | 2.3 | 0.6 | 2,130 | 0.07 |
| DC040 | 72.5 | 4.8 | 7.1 | 14.9 | 0.6 | 0.0 | 6,250 | 0.31 |
| GB020 | 40.6 | 17.7 | 0.6 | 40.6 | 0.6 | 0.0 | 440 | 5.92 |
| GB025 | 29.5 | 13.5 | 0.6 | 55.9 | 0.5 | 0.0 | 660 | 3.95 |
| GB040 | 21.1 | 4.8 | 4.9 | 30.2 | 0.7 | 0.1 | 540 | 3.41 |
| GC045 | 61.5 | 22.2 | 8.4 | 6.4 | 0.9 | 0.5 | 11,900 | 0.38 |
| GM060 | 78.1 | 13.3 | 2.8 | 5.7 | 0.1 | 0.0 | 4,410 | 0.44 |
| HY060 | 71.7 | 12.9 | 12.3 | 2.9 | 0.1 | 0.1 | 11,800 | 0.28 |
| IC020 | 64.9 | 16.8 | 6.1 | 11.8 | 0.3 | 0.0 | 1,740 | 0.99 |
| LD040 | 59.3 | 5.4 | 5.5 | 29.6 | 0.1 | 0.1 | 2,960 | 1.82 |
| LG060 | 66.2 | 16.7 | 9.4 | 7.1 | 0.1 | 0.5 | 4,260 | 0.65 |
| NF009 | 58.4 | 27.2 | 11.4 | 2.7 | 0.2 | 0.0 | 520 | 0.0 |
| NF020[c] | 29.7 | 14.2 | 3.3 | 52.6 | 0.1 | 0.1 | 800 | 2.28 |
| NF050 | 45.6 | 34.1 | 8.3 | 11.2 | 0.3 | 0.6 | 8,370 | 0.45 |
| SC020 | 68.7 | 9.4 | 1.4 | 20.0 | 0.1 | 0.4 | 1,900 | 0.21 |
| SF085 | 50.6 | 26.5 | 5.6 | 14.3 | 2.2 | 0.7 | 12,900 | 0.53 |
| SP020 | 82.6 | 12.0 | 5.2 | 0.0 | 0.1 | 0.1 | 1,560 | 0.0 |

a. Dairy waste application fields represent estimates for milking operations only.
b. Cow numbers represent estimated values for 2000 based primarily on TCEQ inspection information for milking operations. For non-permitted operations without inspected values, head count was estimated as 70 percent of the maximum or 140 head out of a maximum of 199 head.
c. About 8 hectares (20 acres) or about 1 percent of the drainage area above site NF020 is permitted for septic disposal.

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 (Tables 2 and 3). 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.

Because direct monitoring associated with this project did not start until spring 2002, historical or non-direct data associated with other monitoring projects conducted by TIAER were used to help supplement this project. TIAER has collected data from project sites under a variety of quality assurance project plans (QAPPs). Data that may be used from these projects includes water quality, rainfall, and water level (streamflow) information. These QAPPs include the following:

- Data collected by TIAER in the Upper North Bosque River Watershed under the United States Environmental Protection Agency (USEPA) sponsored *Livestock and the Environment: A National Pilot Project (NPP)*. The QAPP is the TIAER document entitled *Quality Assurance Project Plan for the National Pilot Project* (TIAER, 1993), which encompasses data collected from June 1, 1992 through August 31, 1995.
- Data collected by the Brazos River Authority (BRA) and TIAER, as a subcontractor, under the TCEQ Clean Rivers Program. The QAPP is the BRA document entitled *Quality Assurance Project Plan for the Bosque River Watershed Pilot Project* (BRA, 1995) which encompasses data collected from October 1, 1995 through May 31, 1996.
- Data collected by TIAER under the USDA Lake Waco-Bosque River Initiative. The QAPPs are TIAER documents entitled *Quality Assurance Project Plan for the Lake Waco-Bosque River Initiative* (TIAER, 1996, 1997-99, 1999-2000, 2000-2003, and 2003 - 2005), which encompass data collected from September 1, 1996 through September 1, 2005.
- Data collected by TIAER under the Clean Water Act Section 319(h) Nonpoint Source Pollution Control Program for the projects T*echnical and Financial Assistance to Dairy Producers and Landowners of the North Bosque River Watershed within the Cross Timbers Soil and Water Conservation District (01-13)* and *Technical and Financial Assistance to Dairy Producers and Landowners of the North Bosque River Watershed within the Upper Leon Soil and Water Conservation District (01-14)*. These projects include data collected from March 2002 through March 2006 under a TSSWCB and EPA approved QAPP (TIAER, 2004).
- Data collected by TIAER under the Brazos River Authority project Water Quality Monitoring of Wet-Weather Events Upper Bosque Watershed and Upper Leon Watershed. This project includes data collected from 2003 through 2005 under a BRA approved QAPP (TIAER, 2005).

Any data collected during gaps between projects when there was not QAPP coverage were collected and analyzed in the same general manner as the most recently occurring QAPP. Thus, these data were considered appropriate for inclusion in evaluating changes in water quality over time at project monitoring sites.

# 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 wood and range, with a fair amount of land associated with improved pasture and WAFs. Alarm Creek has been monitored on a biweekly basis 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 uses above DB035 are wood and range, with a fair amount of land associated with improved pasture, WAFs, and cropland. A number of dairies are located in the drainage area of DB035. Routine and storm sampling at DB035 was initiated in early 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 or pasture, with some land used as WAFs.

# Goose Branch

**Sites GB020, GB025, and GB040** GB020, GB025, and GB040 are automated sampling sites located in the Goose Branch microwatershed of the South Fork of the North Bosque River, northwest of Stephenville near Lingleville, Texas. Dairying is the predominant land use in the Goose Branch microwatershed. Much of the remaining land area is covered by native range and woodland. GB020 is located on an unnamed road off of Erath County Road (CR) 297, and GB025 and GB040 are located on private property away from roads. Sites GB025 and GB040 are located on separate forks of Goose Branch, both of which discharge into the same PL-566 reservoir. GB020 is located about 1.6 kilometers (1 mile) upstream from GB025. The same dairy operations are associated with both GB020 and GB025, although more dairy waste application fields are associated with GB025. Although somewhat duplicative in effort, both GB020 and GB025 were included in the monitoring program at landowner request. Of note in May 2007, the landowner requested removal of sites GB025 and GB040, and data collection ceased at these locations.

# Green Creek

**Sites GC025 and GC045** Sites GC025 and GC045 are automated sites, located within the Green Creek watershed. Site GC025 is located immediately downstream of FM 847. Site GC045 is located approximately 0.6 km (0.4 miles) upstream of State Highway (SH) 6, 3.3 km (2.0 miles) northwest of Alexander, Texas. The majority of the

land above GC045 is designated as wood or range with some permanent pasture. The majority of the land use above GC025 consists of improved pasture followed by wood or range. Routine and storm sampling was initiated at GC045 in early 2001 and at GC025 in late 2007.

# Gilmer Creek

**Site GM060** GM060 is an automated sampling site located on Gilmer 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 or range with some permanent pasture, cropland, and WAFs.

# 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 and cropland. Only a relatively small portion of the HY060 drainage area (< 5 percent) is associated with WAFs.

# 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. Automated sampling was suspended from March 3, 1998 to May 3, 2001. Routine biweekly grab sampling continued throughout the monitoring period. 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 land use above LD040 is predominantly wood or range, although 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 woodland or range with some improved pasture and cropland. A couple of dairy operations are located within this drainage basin. Routine and storm sampling were initiated at LG060 in 2001.

# North Fork

**Sites NF009, NF020 and NF050** These automated sites are located on or on 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 Scarborough Creek at CR 423. Site NF009 is located on an unnamed tributary of Scarborough Creek on CR 423. The dominant land use above NF020 is dairy farming, while most of the land above NF009 is characterized as range and forage fields. Although these two sites are quite near one another, their hydrology can be different. 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 uses above NF050 are wood, range, and improved pasture.

# 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 during this period when storm sampling was suspended. The majority of the land area above SC020 is characterized by wood or range with a fair amount of land also associated with improved pasture and 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 and woodland or range with much of the remaining land area associated with WAFs or 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, although routine grab sampling was continued. Site SP020 is considered one of the least impacted sites within the watershed with most of its land designated as wood or range.

# Walker Branch

**Site WB050** Site WB050 is located at FM 927, on Walker Branch. The land use above site WB050 consists primarily of wood or range with some improved pasture. Sampling commenced at this site in 2008.

# 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 five-minute 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 water level rise of approximately 4 cm (0.12 ft) occurred. Once activated the sampler would retrieve one-liter sequential samples. The typical sampling sequence for most 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

For a few sites with larger watershed areas (HY060, NF050, and SF085), the sampling sequence was modified to allow for a more extended hydrograph. The sampling sequence at these sites was as follows:

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

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, then downloaded at TIAER headquarters for use with the computer program. The program read the stage level associated with the time interval for each sample collected at a site, correlated the stage to flow using the site's rating curve, and calculated 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 a road culvert. For LD040 and LG060, mathematical fluid mechanics equations were used to estimate flow from culvert flow equations. Of note, site NF009 was moved upstream in February 2006 due to bridge construction work near the site. While efforts were made, insufficient flow measurements were collected at the new location to establish a new rating curve for NF009. A provisional rating curve based on the cross-sectional area used in conjunction with general hydrologic equations was applied to samples collected at the new NF009 location for flow-weighting of samples and determining event mean concentrations.

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.

# Storm Grab Sampling

Storm monitoring of bacteria was added in February 2007 to help characterize bacteria levels in these highly intermittent stream systems, because very few grab samples had been collected during the first several months of the project.

Because sterile conditions are needed for collecting bacteria samples, collecting bacteria samples with the automated samplers would be impractical. Storm bacteria samples were collected as manual grab samples using the same protocols outlined for routine grab samples for *E. coli*. Samples were collected once per day during elevated flows with sampling continuing at least one day after flow levels had receded to evaluate changes in *E. coli* concentrations with changes in flow. Elevated flows were defined by a rise in the water level of about 1.5 inches, which was also the rise used to trigger automated samplers for storm sampling. To accommodate lab and field staff due to the relatively short holding times associated with bacteria samples (8 hours), storm sampling of bacteria occurred only during the standard work week (Monday – Friday) and not on weekends.

# Grab Sampling

Routine grab sampling at all sites was performed on a biweekly basis when flow was present. Samples were not collected at sites that were dry or pooled. 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 by placing samples in coolers with ice, was performed in the laboratory. Beginning in October 2003, sampling 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, 2003).

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 filtration and/or acidification were taken from this bottle after it had been agitated thoroughly to ensure total mixing of sediments. Samples that required field filtration were filtered through a 0.45 -micron filter using a 50 CC or larger syringe. 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. A fresh filter was then used to obtain an aliquot for $PO_4$-P analysis with the syringe, 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 allow field filtration with the syringe, a comment was added to the change 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, which were also analyzed for storm samples, routine grab samples were analyzed for *Escherichia coli* (*E. coli*) bacteria. Of note, grab samples prior to April 2004 were analyzed for *E. coli* and fecal coliform (FC). 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

Ammonia-nitrogen ($NH_3$-N), nitrite-nitrogen plus nitrate-nitrogen ($NO_2$-N+$NO_3$-N), total Kjeldahl nitrogen (TKN), $PO_4$-P or SRP, total-P (total P), and total suspended solids (TSS) were evaluated for both the routine grab and storm samples (Table 5). 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 the 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.

**Table 5** Constituents and methods of analysis for water quality samples.

| Constituent | Abbreviation | Units | Analysis Method[a] | Description |
|---|---|---|---|---|
| Ammonia-nitrogen | $NH_3$-N | mg/L | EPA 350.1 | Inorganic form of nitrogen that is readily soluble and available for plant uptake. Elevated levels are toxic to many fish species. |
| Nitrite-nitrogen + nitrate-nitrogen | $NO_2$-N+$NO_3$-N | mg/L | EPA 353.2 | Inorganic form of nitrogen that is readily soluble and available for plant uptake. Considered the end product in the conversion of N from the ammonia form to nitrite then to nitrate under aerobic conditions. |
| Total Kjeldahl nitrogen | TKN | mg/L | EPA 351.2 modified[b] | Organic and ammonia forms of nitrogen are included in TKN. |
| Orthophosphate-phosphorus | $PO_4$-P or SRP | mg/L | EPA 365.2 | Inorganic form of phosphorus that is readily soluble and available for plant uptake. Soluble reactive phosphorus (SRP) is another name for this constituent. |
| Total phosphorus | Total-P | mg/L | EPA 365.4 modified[b] | Represents both organic and inorganic forms of phosphorus. |
| Total suspended solids | TSS | mg/L | EPA 160.2 | Measures solid materials, such as clays, silts, sand, and organic matter, suspended in the water column. |
| Fecal coliform | FC | colonies /100 mL | SM 9222D | Indicator of public health hazards from infectious microorganisms |
| *Escherichia coli* | *E. coli* | colonies/100 mL or MPN (most probable number)/ 100 mL | SM 9222G or SM 9223-B[c] | Indicator of public health hazards from infectious microorganisms |

a. EPA refers to *Methods for Chemical Analysis of Water and Wastes* (USEPA, 1983). SM refers to the *Standard Methods for the Examination of Water and Wastewaters*, 18th edition (APHA, 1992).
b. Modification of TKN and TP methods involved using copper sulfate as the catalyst instead of mercuric oxide.
c. Analysis of *E. coli* was changed from SM 9222G to SM 9223-B in April 2004.

Left censored data indicated as method detection limits (MDLs) or ambient water reporting limits (AWRLs) were entered into the database as one-half the MDL following recommendations by Gilliom and Helsel (1986) and Ward et al. (1988). Starting in 2003, some TIAER projects, but not all, started to require AWRLs set by 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 parameter.

# Statistical Evaluation Methods

## Comparisons Between Sites

To evaluate existing conditions at microwatershed sites, basic summary statistics including mean, median, and standard deviation were calculated for both 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 between January 2001 through December 2007 after initiation of the TMDL Implementation Plan.

To compare water quality between sites, an analysis of variance (ANOVA) was performed on each constituent on EMCs for storm data and for routine grab samples. For routine grab data, the number of samples collected per site varied considerably due to the intermittent nature of these small stream sites. For example, at site GB025 only two routine grab samples were collected between January 2001 and December 2007, while at site DC040, 158 samples were collected (Table 6). For comparisons of routine grab data sites GB020 and GB025 were excluded as having too few samples for a meaningful comparison. After excluding sites GB020 and GB025, only sampling periods when 75 percent or more of the sites were flowing were evaluated to provide a more representative time period for comparison between sites.

**Table 6** Number of routine grab samples and storm events monitored by sampling site between January 2001 and December 2007.

| Site | Number of Routine Grab Samples | Number of Storm Events Monitored |
|---|---|---|
| AL020 | 83 | 78 |
| DB035 | 49 | 84 |
| DC040 | 158 | 98 |
| GB020 | 7 | 47 |
| GB025 | 2 | 57 |
| GB040 | 49 | 65 |
| GC045 | 79 | 65 |
| GM060 | 102 | 69 |
| HY060 | 92 | 71 |
| IC020 | 56 | 78 |
| LD040 | 44 | 62 |
| LG060 | 74 | 46 |
| NF009 | 68 | 64 |
| NF020 | 26 | 74 |
| NF050 | 47 | 75 |
| SC020 | 109 | 81 |
| SF085 | 127 | 142 |
| SP020 | 106 | 81 |

Storm events showed less variability in the number of events between sites with generally 40 to 70 events per site (Table 6). Of note, SF085 had 142 storm events monitored. It is suspected that impervious surfaces associated with nearby urban areas contributed to the frequency of events at SF085. For ANOVA and LSD comparisons, all storm event data were used.

Prior to performing ANOVA, constituent data sets were evaluated to determine if the assumptions of normality and equal variances were met. The Shapiro-Wilk statistic was used to test for normality (SAS, 1990), while the Harley's test was used to test for equal variances (Ott, 1984). If significant differences were indicated at $\alpha$=0.05 by the ANOVA, a test of least significant differences (LSD) was applied as a multiple comparison test to distinguish specific differences between sites (Ott, 1984). The purpose of these comparisons was to give a general idea of relative water quality between sites and indicate areas that might be of interest to TSSWCB for targeting nonpoint source management efforts.

For nutrient, TSS, and bacteria data represented by routine grab samples and nutrient and TSS data represented by EMCs, a natural log transformation allowed a better fit to the assumptions of normality and equal variances. In some cases even when transformed, the assumptions for normality and equal variances were still not met at $\alpha$=0.05. In these cases when the assumptions were still not met, but the transformed data were indicated to more closely meet these assumptions than the untransformed data, the transformed data were used in the ANOVA. These deviations from the assumptions of normality and equal variances were considered to have a minimal impact of the validity of the ANOVA test, because of the inherent robustness of ANOVA to violations in these assumptions (Spooner and Line, 1993). For all nutrient and TSS constituents, a natural-log transformation was implemented prior to evaluating the data using ANOVA.

For field parameters, pH, DO, and water temperature data met assumptions for normality and equal variances without the need for considering data transformations. Of note, pH data are already on a log scale as the log of the hydrogen ion concentration. A natural-log transformation was applied to conductivity data to better fit the assumption of equal variances.

# Evaluations of Bacteria with Flow

Bacteria samples were evaluated in response to flow conditions at each site using two regression methods. Parametric ordinary least squares (OLS) regression was applied assuming a simple linear relationship between *E. coli* concentrations and flow. Nonparametric locally weighted regression and smoothing scatterplots (LOWESS) regression was applied, which does not assume a predefined functional form in the concentration-flow relationship, but establishes a generally form or trend of the relationship. LOWESS (also known as LOESS) regression approximates the regression function locally around each point rather than for the full data set at once (see Cleveland, 1979). Both routine grab and storm grab samples were included in the evaluation of bacteria concentrations with flow. Flow and bacteria concentrations were natural log transformed prior to applying the regression techniques due to the distribution of the data.

# Comparisons with Land Use

To evaluate the impact of land use on water quality, a correlation analysis was applied using the median of EMCs from storm events or the geometric mean of storm bacteria

samples with the percent land use by category within each microwatershed as provided in Table 3. The correlation analysis was conducted using the PROC CORR function of the SAS analysis system (SAS, 2000).

# Trend Analysis Using Kendall's Tau

To evaluate short-term trends in storm data collected from 2001 through 2007 during the implementation phase of the TMDL, trend analysis was performed on volume-weighted storm event data summarized on a monthly basis. The nonparametric Kendall's tau test statistic was used as described in Reckhow et al. (1993) based on monthly data. 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 at a given site were summed and loadings were divided by the total storm volume to obtain a monthly volume-weighted concentration. 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. The volume of water in a stream can have a distinct impact on water quality concentrations, so volume adjustment between months was conducted prior to trend analysis as an ancillary variable following procedures outlined by Helsel and Hirsch (1992).

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, 1992):

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

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.

# Before and After Analysis Using ANCOVA

To specifically evaluate the impact of the manure composting program on water quality, a "before" and "after" analysis was conducted on the water quality data from five long-term monitoring sites (GB025, GB040, IC020, NF020, and SP020). All five of these sites had historical or non-direct water quality data starting in 1997 or earlier

(Table 2). Earlier analyses of data at sites NF020, GB025, GB040, and IC020 indicated that certain runoff events may have been impacted by effluent discharges from dairy retention control structures rather than solely from nonpoint source runoff (Bekele and McFarland, 2004a). In most cases this could not be verified; but to isolate the impact of the manure composting program, it was important that potential contributions from sources other than nonpoint source runoff be removed. Consequently, a separate data set was constructed deleting data points suspected to be impacted by effluent discharges. Storms were not included in the before and after analysis if they contained samples with uncharacteristically high $NH_3$-N concentrations (> 5.0 mg/L), because wastewater effluent from dairies is typically associated with high ammonia values. Some differences were observed in results between the full and reduced data sets (Bekele and McFarland, 2004a); therefore, only the reduced data set was evaluated for this report.

The EMCs "before" and "after" initiation of the manure composting program were analyzed using both parametric and nonparametric statistics as a step trend (Hirsch, 1988). Step trend procedures were used because there were gaps in the data record at some sites breaking the data into two distinct time periods (Table 2) and because there was a known event (the initiation of the manure composting program) that was expected to result in a change in water quality (Helsel and Hirsch, 1992). Data collected prior to initiation of the composting program in November 2000 was designated as the "before" period while data collected after November 2000 was designated as the "after" period. The data were analyzed as a "before/after" monitoring design (Grabow et al., 1999; Smith, 2002; Spooner et al., 1985) using analysis of covariance (ANCOVA) and the nonparametric Wilcoxon rank sum (WRS) procedures (SAS, 2000).

In the ANCOVA, average flow for each storm event was used as the covariate and two regression lines are developed relating concentration to flow, one each for the before and after periods. The ANCOVA consists of multiple steps that determine the statistical significance of: 1) the regression equations relating streamflow and concentration from the two monitoring periods; 2) the equality of the slopes of the two regression lines; and 3) the difference between the intercepts of the two regressions for the two monitoring periods (Littell et al., 1996; NRCS, 1997). For ANCOVA to clearly indicate significant differences between the before and after periods, all three steps should indicate significant differences. To satisfy assumptions of homogeneity of variance and homogeneity of regression, ANCOVA was performed on the natural log-transformed data (Littell et al., 1996). Estimated means from the ANCOVA were flow adjusted based on the average flow for each event. The ANCOVA evaluates differences among treatment level means (before and after periods) that would occur if all concentrations had the same streamflow (Keppel, 1991). Of note, estimated mean concentrations for the before period vary slightly from previous reports, because of differences in flow during the after period with the monitoring and analysis of additional storm events (see Ott, 1984).

In the WRS analysis, EMCs were flow adjusted prior to analysis using locally weighted regression and smoothing scatterplots (LOWESS) with a smoothing coefficient of 0.5 (Helsel and Hirsh, 1992; Bekele and McFarland, 2004b), except site SC020. At site SC020 the flow-concentration relationship changed over time due to

suspected damming of the stream upstream of the sampling site. For all sites except SC020, the residuals from LOWESS regression were then used in the WRS test. For SC020, EMCs were evaluated directly using the WRS test.

Both parametric and nonparametric procedures were implemented because at one site (SC020) assumptions associated with the ANCOVA could not be fully met. In addition, the application of both parametric and nonparametric methods on the same data set is considered useful because it provides assurance in the interpretation of results (NRCS, 1997). A step trend confirmed by both analyses is considered more meaningful than one indicated by only one test. Statistical significance was evaluated at an $\alpha = 0.10$ probability level.

# CHAPTER 4

# Results and Discussion

## Comparisons Between Sites

### Routine Grab Data

Basic statistics for routine grab data are presented in Appendix A for data collected between January 2001 and December 2007. Sites GB020 and GB025 are included in Appendix A for reference purposes however are excluded in the following discussion due to the low number grab of samples collected at each location. Only two grab samples were collected at GB020 and five at GB025 during the monitoring period (Table 6). Because of the highly intermittent nature of these microwatershed sampling sites, many times only a few sites were flowing during a routine grab sampling event. To make comparisons between sites more comparable, grab sampling events were included only if 75 percent or more of the sites were flowing during a given sampling event.

Of the 16 sites, the highest geometric mean $NH_3$-N and $NO_2$-N+$NO_3$-N concentrations from routine grab samples occurred at GB040, while the highest TKN concentrations occurred at site NF020 (Figures 4a, b, and c). The lowest geometric mean nitrogen concentrations consistently occurred at SP020 for all three forms of nitrogen. For $NH_3$-N and $NO_2$-N+$NO_3$-N, there appeared to be a fair amount of overlap in similarity of geometric mean concentrations except at very low and high concentrations. For $NH_3$-N, geometric mean concentrations were at or below 0.10 mg/L at all sites except LD040 and GB040. For $NO_2$-N+$NO_3$-N, geometric mean concentrations were below 2 mg/L at all sites but GC045 and GB040.

For phosphorus constituents, sites HY060 and SP020 had the lowest geometric mean $PO_4$-P and total-P concentrations and sites GB040 and NF020 had the highest concentrations (Figures 5a and b). For both $PO_4$-P and total-P there was a clear split in the grouping of similar sites between LG060 and AL020. The geometric mean at LG060 was 0.042 mg/L $PO_4$-P and 0.13 mg/L total-P and at AL020 0.089 mg/L $PO_4$-P and 0.21 mg/L total-P.

A general ordering of sites from highest to lowest nutrient concentrations was determined based on an average of the ranking of the geometric mean for $NH_3$-N, $NO_2$-N + $NO_3$-N, TKN, $PO_4$-P and total-P.

GB040>LD040>NF020>DB035>NF050>IC020>AL020>NF009>SF085>LG060=GC045 >SC020>GM060>DC040>HY060>SP020

**Figure 4** Geometric mean nitrogen concentrations for routine grab samples at sites for a) $NH_3$-N, b) $NO_2$-N + $NO_3$-N, and c) TKN collected between January 2001 and December 2007. Data limited to sampling periods when 75 percent or more of sites were flowing. Different letters indicate significantly different mean values at α=0.05 based on a test of LSD.

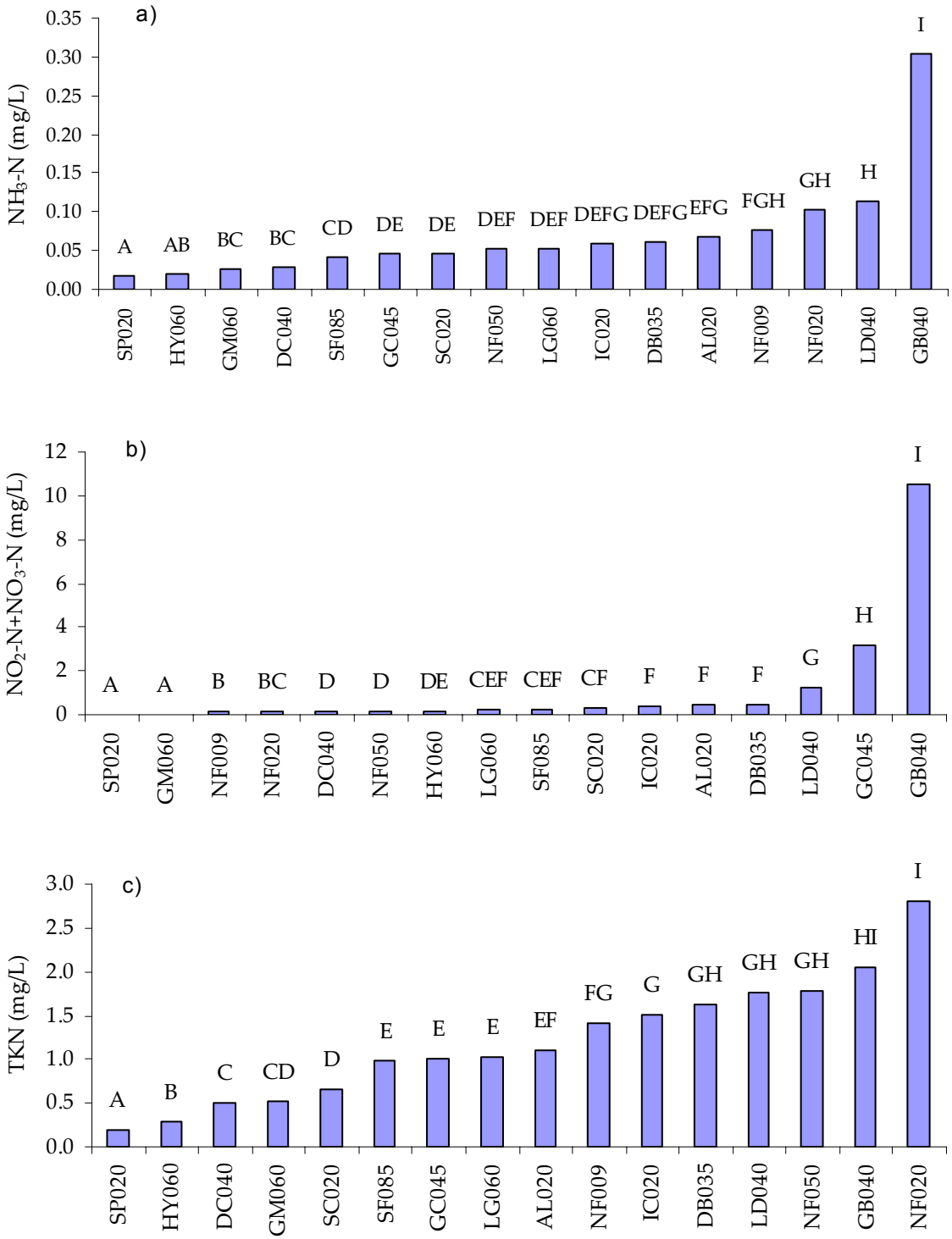
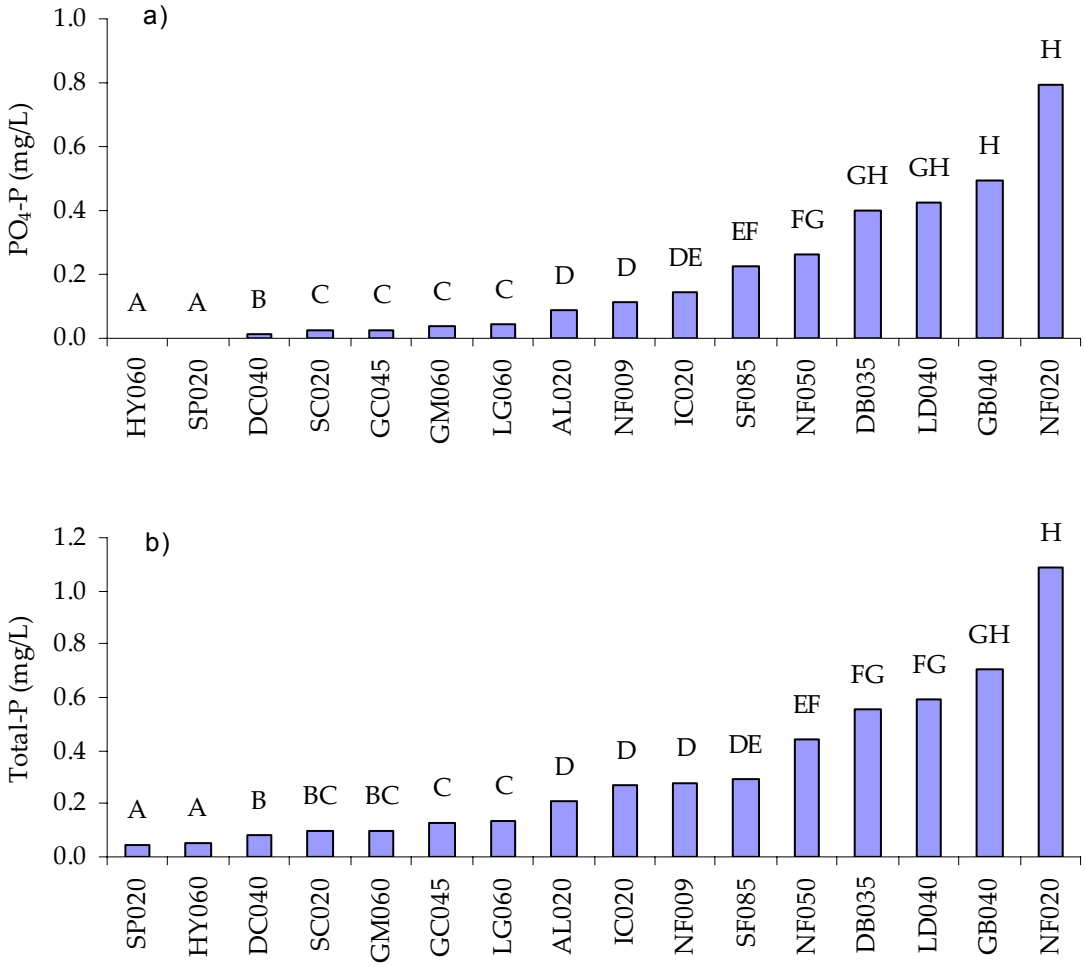


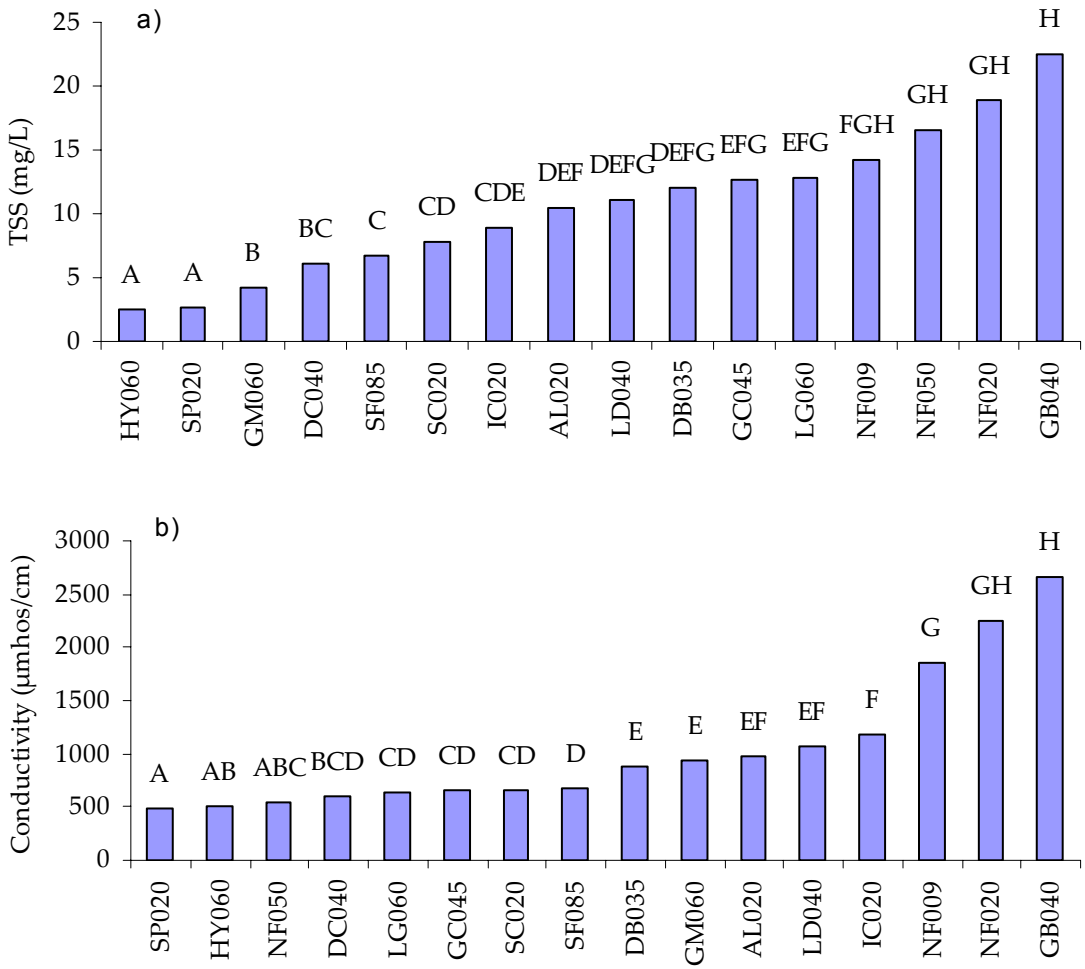
**Figure 5** Median phosphorus concentrations for routine grab samples at sampling sites for a) $PO_4$-P and b) total-P collected between January 2001 and December 2007. Data limited to sampling periods when 75 percent or more of sites were flowing. Different letters indicate significantly different mean values at α=0.05 based on a test of LSD.




This ranking is not an assessment of water quality but is provided to help identify stations with higher nutrient concentrations where assistance with nutrient control practices might be targeted. Mean concentrations for nutrients in grab samples were generally reflective of major land uses in the drainage area above each site (Table 3). Microwatersheds comprising a large percent of WAFs consistently had some of the highest nutrient concentrations, while microwatersheds comprised primarily of wood/range generally had some of the lowest nutrient concentrations.

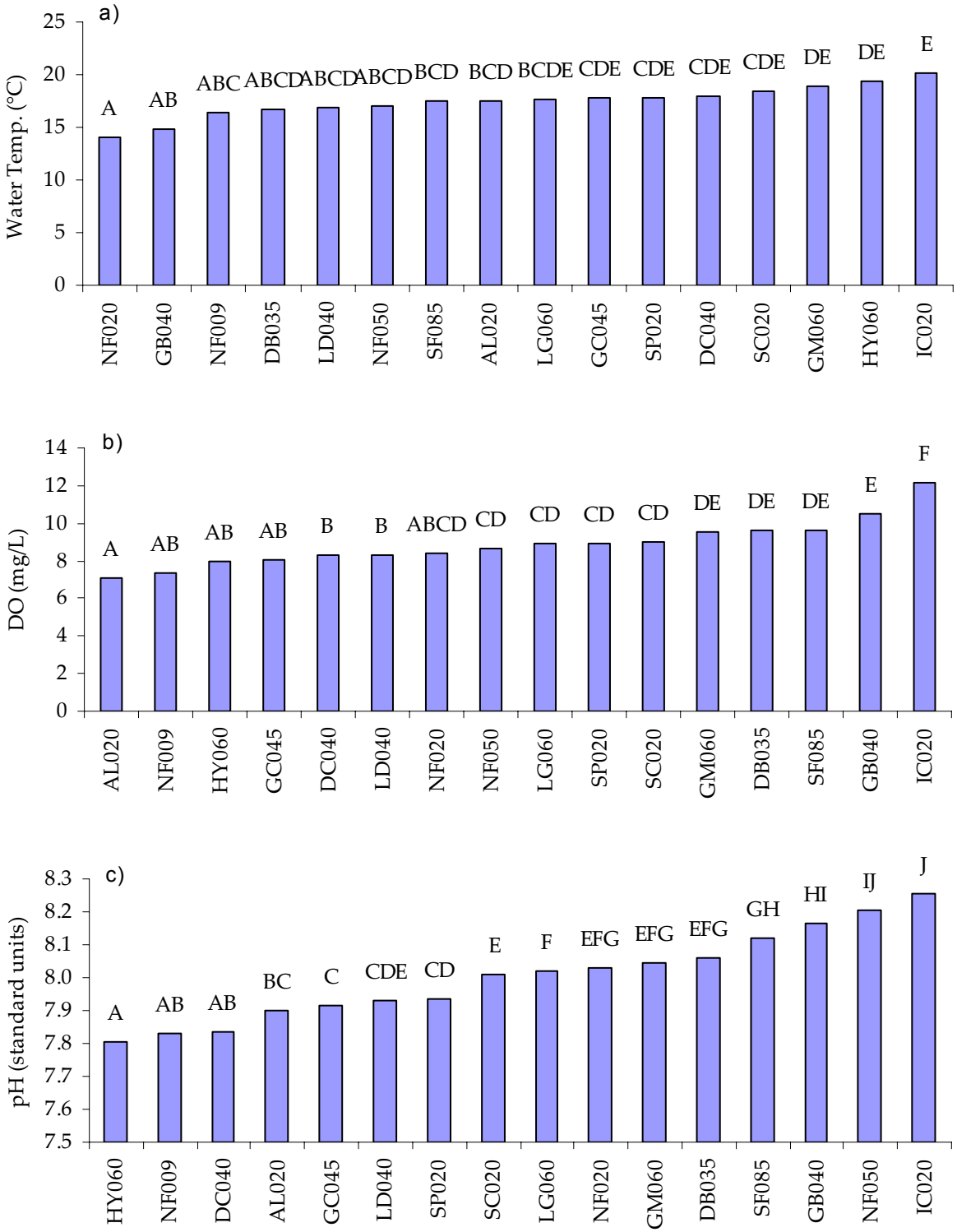
Geometric mean concentrations for TSS and conductivity for routine grab samples showed trends similar to those found for the nutrient constituents with sites SP020 and HY060 having some of the lowest concentrations (Figures 6a and b). For conductivity, site NF050 was bit of an anomaly in that this site was grouped with the lowest conductivity values, but for most other constituents, site NF050 was grouped at the higher end of the concentration range in comparisons between sites.

**Figure 6** Geometric mean a) TSS concentrations and b) conductivity values for grab samples collected between January 2001 and December 2007. Data limited to sampling periods when 75 percent or more of sites were flowing. Different letters indicate significantly different mean values at α=0.05 based on a test of LSD.




Differences in mean water temperature were indicated and ranged from a mean of 14ºC at site NF020 to 20ºC at IC020 (Figure 7a). These differences are likely due to varying frequencies of intermittent and ephemeral flow between sites throughout any given year. Sites that continue to flow during warmer months will likely have higher average temperatures than sites that typically cease flowing during the same period. Differences in mean temperature are also likely due to differences in shading associated with vegetative canopy cover characteristics at the various sites. For example, site NF020 is located within a densely vegetated riparian area, while IC020 is located in the middle of a pasture with no overhanging vegetation.

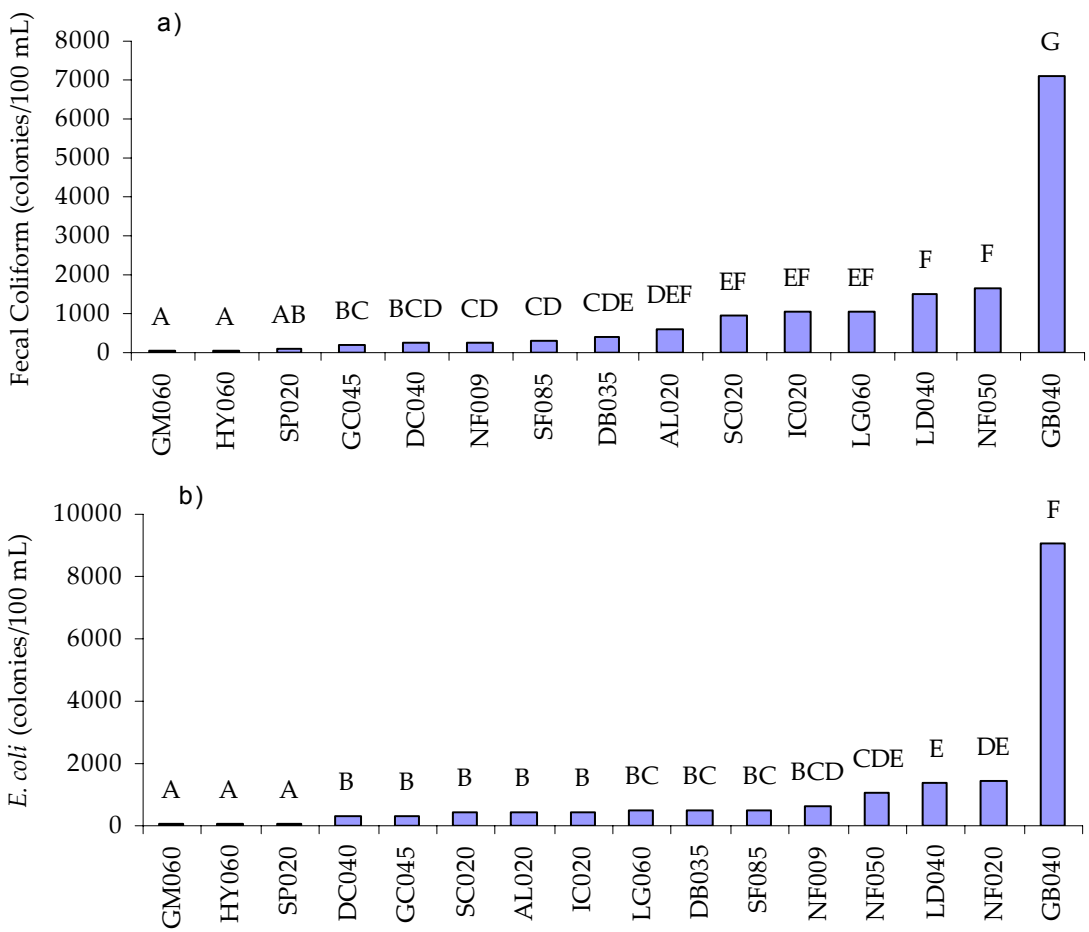
**Figure 7** Mean a) water temperature b) dissolved oxygen, and c) pH for grab samples collected between January 2001 and December 2007. Data limited to sampling periods when 75 percent or more of sites were flowing. Different letters indicate significantly different mean values at α=0.05 based on a test of LSD.



While site differences were noted for mean DO and pH (Figures 7b and c), these differences were fairly minor and well within expected limits for aquatic life use. All DO concentrations were well above 5 mg/L, a common screening level used by TCEQ for instantaneous DO measurements (TCEQ, 2007). Mean pH values also were well within the general range of 6.5 to 9.0 considered for most aquatic life uses (TCEQ, 2007). Of note, aquatic life use evaluations for DO should be based on 24-hr measurements rather than instantaneous measurements, because DO often follows a diurnal cycle with lows generally occurring in the early morning prior to the resumption of photosynthetic processes. Measurements were generally taken mid-morning between 9am and noon as instantaneous measurements.

Similar to nutrients, the highest geometric mean concentration for fecal coliform and *E. coli* for grab samples was indicated at site GB040 and the lowest concentrations were indicated at sites DC040, HY060, and SP020 (Figures 8a and b). Of note, only five fecal coliform samples were collected at NF020 during the study, so NF020 is not represented in Figure 8a. Also, fecal coliform was collected only through March 2004.

**Figure 8** Geometric mean a) fecal coliform b) *E. coli* concentrations for grab samples collected between January 2001 and December 2005. Data limited to sampling periods when 75 percent or more of sites were flowing. Different letters indicate significantly different mean values at α=0.05 based on a test of LSD.



# Storm Event Data

Basic statistics for storm events were based on event mean concentrations associated with each event rather than individual samples (Appendix B). With regard to mean concentrations for nutrients and TSS, generally storm concentrations were higher than concentrations from routine grab samples, although some exceptions occurred for specific sites and constituent combinations. Hydrograph information indicating the timing of storm events is shown in Appendix C.

The highest geometric mean storm concentrations for $NH_3$-N and TKN were indicated at sites GB020, GB025, and GB040 with concentrations greater than 0.3 mg/L for $NH_3$-N and greater than 5 mg/L for TKN (Figures 12a and c). The highest geometric mean storm concentrations for $NO_2$-N+$NO_3$-N occurred at sites GB020, GB040, and GC045 with concentrations greater than 1.8 mg/L (Figure 12b). The lowest concentrations for nitrogen constituents consistently occurred at SP020.

For $PO_4$-P and total-P, the highest geometric mean storm concentrations were at GB020 followed by GB025, and then GB040 (Figure 13a and b). Geometric mean concentrations of $PO_4$-P exceeded 1 mg/L at sites GB020 and GB025, while for total-P, geometric mean storm concentrations at sites GB020, GB025, and GB040 all exceeded 2 mg/L. The lowest mean $PO_4$-P and total-P concentrations occurred at sites HY060 and SP020 with mean $PO_4$-P concentrations less than 0.02 mg/L and total-P concentrations less than 0.2 mg/L.

Geometric mean TSS concentrations for storm events followed a slightly different pattern from $PO_4$-P and total-P in that site GB020 had fairly low storm concentrations rather than some of the highest concentrations (Figure 13c). In general it would be expected that TSS concentrations would be closely associated with total-P concentrations as a measure of particulate matter moved during storm events; however, comparisons of the ratio of $PO_4$-P to particulate P in total-P indicate that nearly 65 percent of the total-P measured at GB020 during storm events was associated with $PO_4$-P or soluble P (Figure 14).

As with grab samples, higher mean storm concentrations for nutrients and TSS appeared to be most often associated with microwatersheds with a larger proportion of land area associated with WAFs. Lower storm concentrations were generally associated with microwatershed representing predominately wood/range (Table 3).

A general ordering of sites from highest to lowest overall nutrient concentrations was determined based on the average of the ranking of the geometric mean. For $NH_3$-N, $NO_2$-N+$NO_3$-N, TKN, $PO_4$-P, and total-P, the following rank order was indicated:

GB020>GB040>GB025>NF020>LD040>IC020>DB035>NF009>NF050>LG060>AL020>GC045>SC020>SF085>GM060>DC040>HY060>SP020

This ranking was fairly similar to the ranking indicated for routine grab samples for the high and low end of the scale, although some switching of the ordering of sites occurred in between.

**Figure 9** Geometric mean nitrogen concentrations for storm events by site for a) $NH_3$-N, b) $NO_2$-N + $NO_3$-N, and c) TKN monitored between January 2001 and December 2007. Data limited to sampling periods when 75 percent or more of sites were flowing. Different letters indicate significantly different mean values at α=0.05 based on a test of LSD.

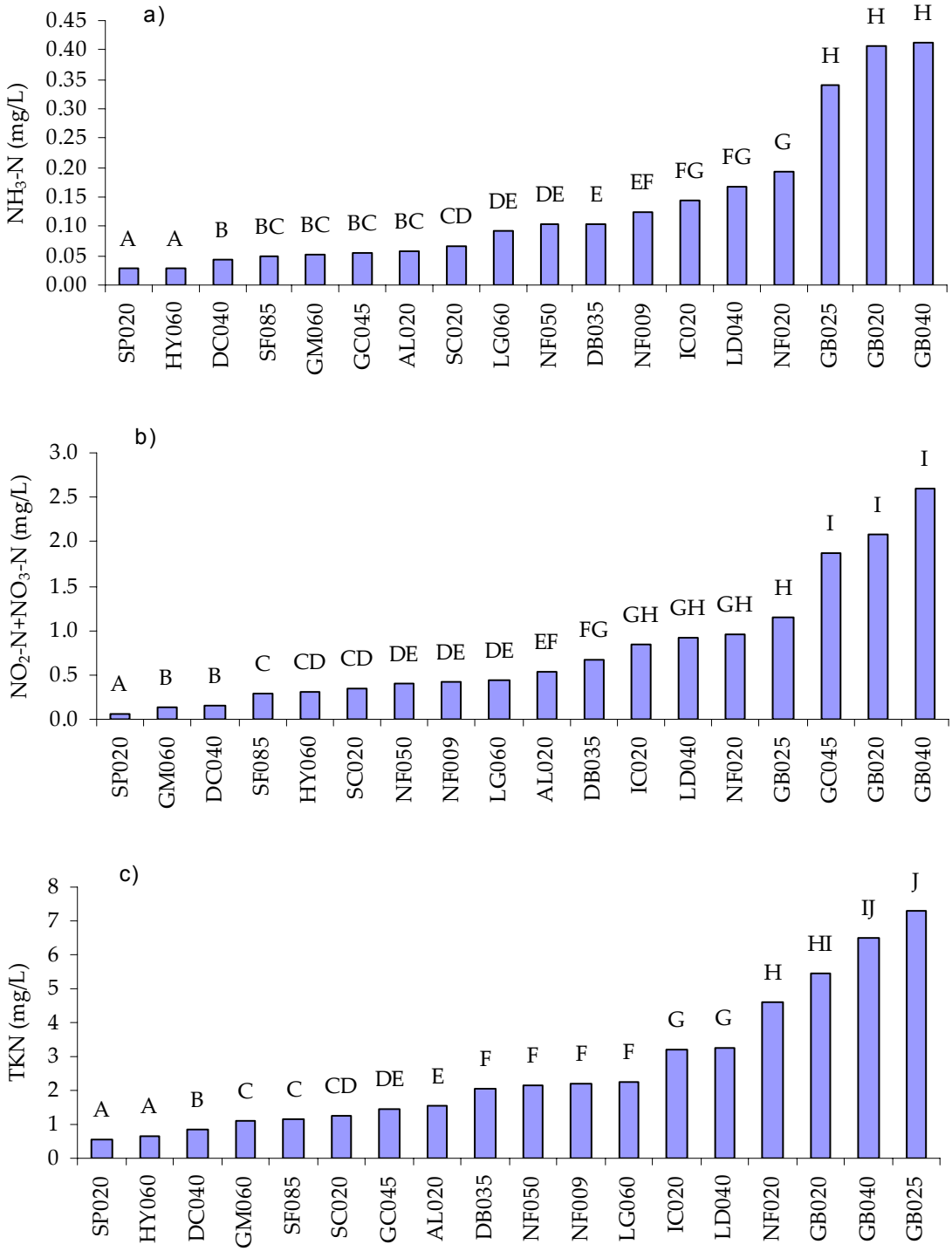


**Figure 10** Geometric mean phosphorus and TSS concentrations for storm events by site for a) $PO_4$-P, b) total-P, and c) TSS monitored between January 2001 and December 2007. Data limited to sampling periods when 75 percent or more of sites were flowing. Different letters indicate significantly different mean values at α=0.05 based on a test of LSD.

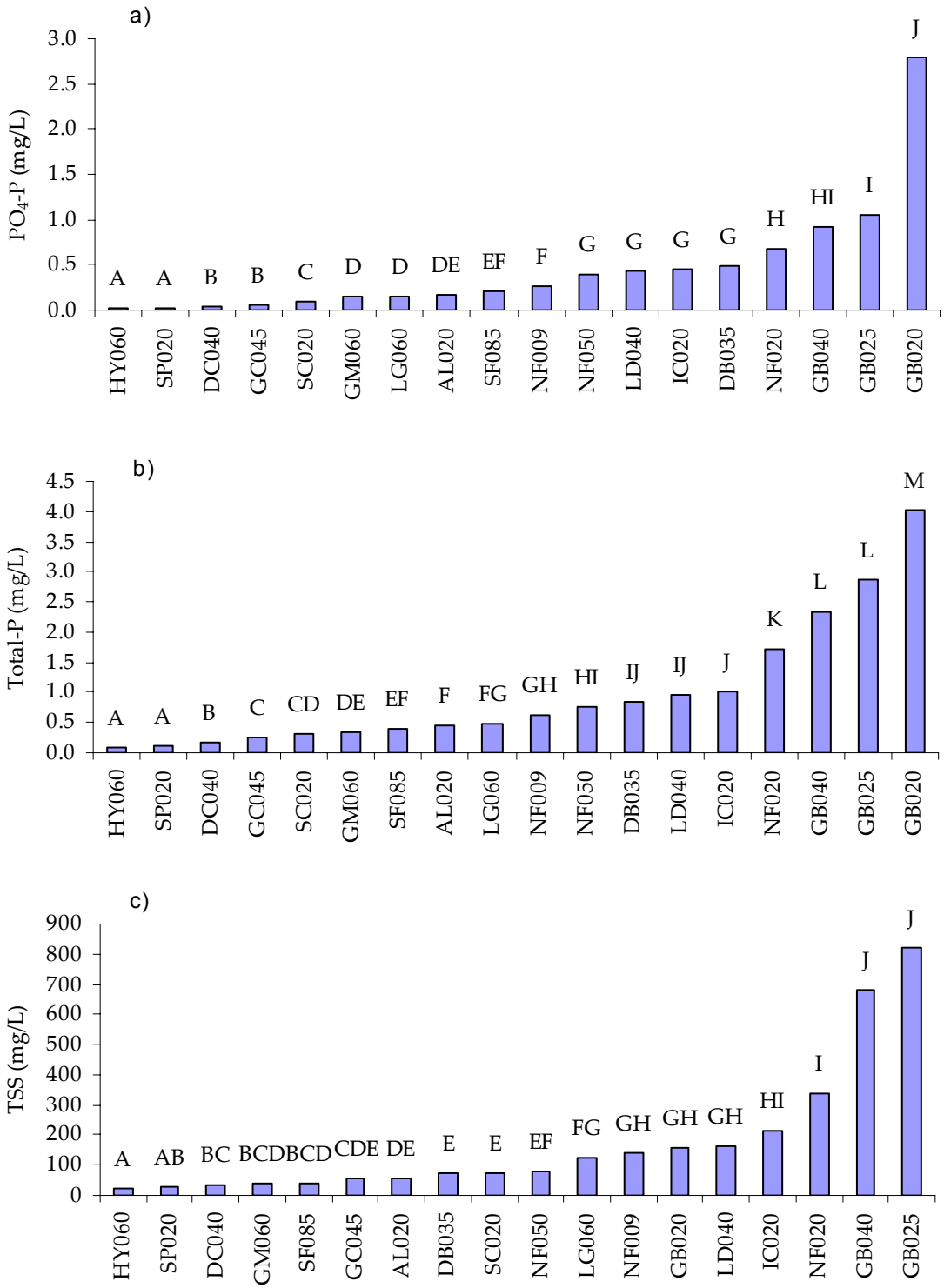
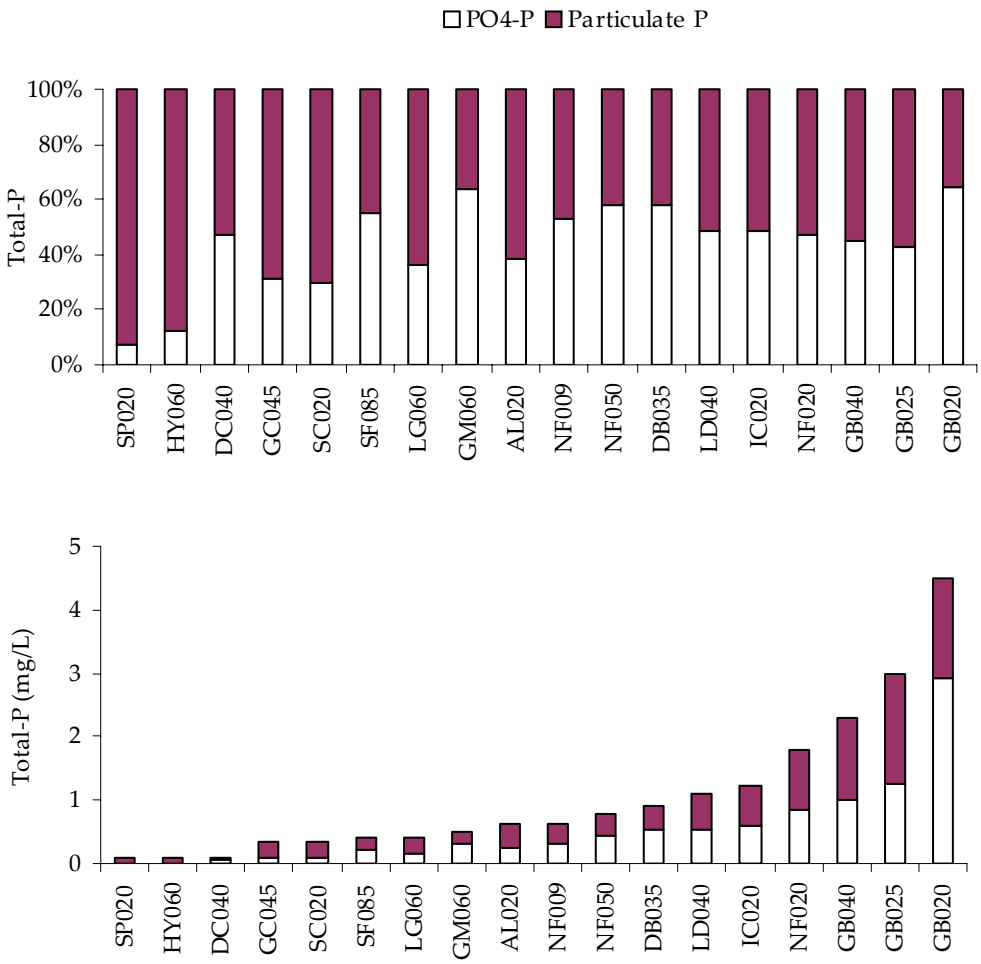
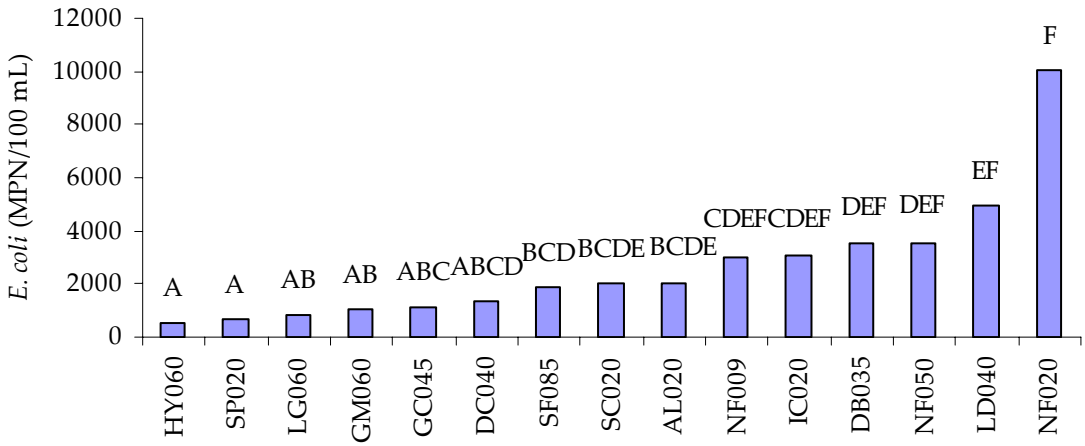


**Figure 11** Proportions of $PO_4$-P and particulate P comprising total-P from storm events monitored between January 2001 and December 2007.




Geometric mean *E. coli* concentrations obtained from grab samples collected during storm events between April 1, 2007 through December 31, 2007 were compared between all sites with the exception of sites GB020, GB025, and GB040 (Figure 15). The beginning date of April 1, 2007 was selected, because this date represents the initiation of bacteria sample collection during storm events for all sites and allowed for comparison of a more similar number of samples between sites. The largest geometric mean storm concentrations for *E. coli* were indicated at sites LD040 and NF020 with concentrations greater than 4,900 (colonies/100 mL). Similar to nutrient and TSS concentrations, the lowest *E. coli* concentrations were indicated at sites HY060 and SP020.

**Figure 12** Geometric mean *E. coli* concentrations for grab samples collected during storm events by site monitored between April 1, 2007 and December 31, 2007. Different letters indicate significantly different mean values at α=0.05 based on a test of LSD.




# Bacteria Concentrations Related to Flow

Because relatively few grab samples had been collected during the early portion of the project, the project work plan was amended in January 2007 to include sampling of bacteria during elevated flows or storm events. This task was added to better characterize bacteria concentrations with regard to flow conditions at these highly intermittent stream sites. Historical storm grab data for bacteria were also available from a TIAER project for the BRA that included wet-weather bacteria samples collected in 2003 through 2005 for many of the same sampling sites (TIAER, 2005).

Instantaneous flow was determined for each bacteria sample based on the site rating curve and stream level. Correlation analysis indicated a significant positive relationship between concentration and flow at almost all of sampling sites (Table 7). Of note, site NF009 was not included in this evaluation, because site NF009 was moved in February 2006 due to bridge construction work near the site and the rating curve for estimating flow at the new location was incomplete. Site GB025 was not included because very few bacteria samples were collected at this site (two routine grabs and one storm grab). Bacteria concentrations at sites GB020, LG060, and NF050 indicated a lot of scatter and were not significantly related to flow conditions.

**Table 7** Correlation of *E. coli* concentrations with flow by sampling site.

| Site | Correlation Coefficient | p-value | Number of Samples |
|---|---|---|---|
| AL020 | 0.56 | <0.0001 | 182 |
| DB035 | 0.49 | <0.001 | 72 |
| DC040 | 0.63 | <0.0001 | 163 |
| GB020 | 0.03 | 0.8832 | 24 |
| GB040 | 0.58 | <0.0001 | 64 |
| GC045 | 0.55 | <0.0001 | 81 |
| GM060 | 0.70 | <0.0001 | 111 |
| HY060 | 0.75 | <0.0001 | 211 |
| IC020 | 0.49 | <0.0001 | 137 |
| LD040 | 0.68 | <0.0001 | 70 |
| LG060 | 0.14 | 0.2152 | 84 |
| NF020 | 0.54 | <0.0001 | 82 |
| NF050 | 0.05 | 0.6554 | 75 |
| SC020 | 0.41 | <0.0001 | 188 |
| SF085 | 0.41 | <0.0001 | 124 |
| SP020 | 0.65 | <0.0001 | 120 |

Simple or OLS regression was applied to data from sites that indicated significant correlation coefficients (Table 8). Most regression coefficients were less than 0.50 indicating that the majority of the variability in bacteria concentrations was not associated with flow. Even though flow is a significant explanatory variable, other factors, such as temporal fluctuations in animal populations and the inherent variability in bacteria concentrations, make the analysis of bacteria concentration data complex. While slopes and intercepts for many of the sites seemed somewhat similar, there was so much scatter in the data that it was difficult to group sites to determine if sites had similar relationships. Although a positive trend of bacteria concentrations with flow was indicated for most sites, visual review of the data indicated that this relationship may not be linear.

**Table 8** Linear regression parameters relating bacteria concentration to flow by site. All regression equations were significant with a p-value < 0.0001. *E. coli* represented in units of colonies or MPN per 100 mL and flow in units cms.

| Site | Intercept ln(*E. coli*) | Slope ln(*E. coli*)/ ln(Flow) | $R^2$ |
|---|---|---|---|
| AL020 | 6.32 | 0.625 | 0.31 |
| DB035 | 7.01 | 0.522 | 0.24 |
| DC040 | 5.18 | 0.637 | 0.39 |
| GB040 | 10.1 | 0.441 | 0.34 |
| GC045 | 4.65 | 0.545 | 0.31 |
| GM060 | 0.339 | 1.58 | 0.50 |
| HY060 | 3.45 | 0.881 | 0.57 |
| IC020 | 7.89 | 0.618 | 0.24 |
| LD040 | 5.59 | 1.09 | 0.46 |
| NF020 | 9.11 | 0.522 | 0.30 |
| SC020 | 6.40 | 0.439 | 0.17 |
| SF085 | 6.22 | 0.506 | 0.17 |
| SP020 | 5.20 | 0.501 | 0.43 |

To more closely evaluate patterns in the relationship of bacteria concentration with flow, LOWESS regression was applied to each site. Plots of the LOWESS regression results are presented in Appendix D. Patterns generally indicated a positive relationship of bacteria concentrations with flow, although in some cases there appeared to be a leveling off or slight increase in concentrations at very low flow conditions as indicated for example at sites DB035 and SF085 (Figures 9 and 10). LOWESS regression applied to the data from all sites combined indicated a general increase in bacteria concentrations with flow (Figure 11), but also showed the extreme scatter that often accompanies bacteria data, and other nonpoint source driven constituents, making them difficult to interpret.

**Figure 13** Relationship of bacteria concentration to flow at site DB035. Dashed line represents LOWESS regression results.

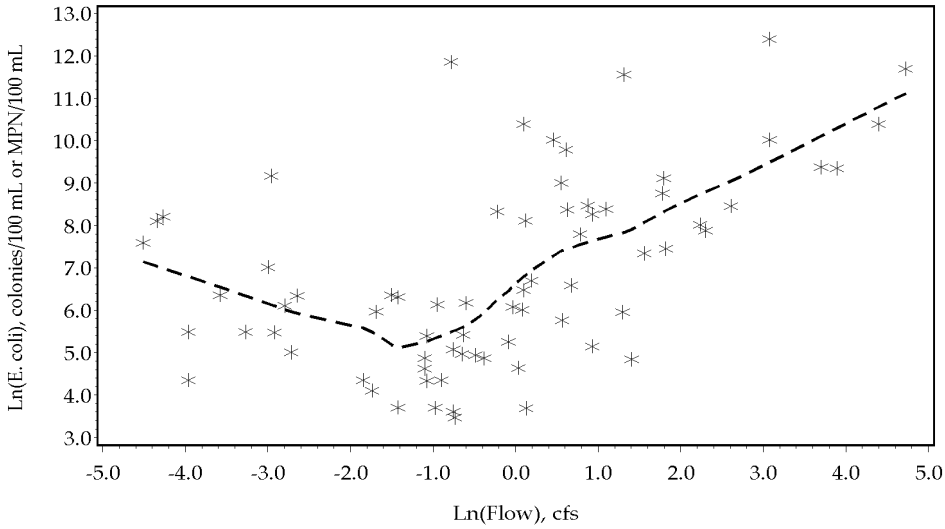



**Figure 14** Relationship of bacteria concentration to flow at site SF085. Dashed line represents LOWESS regression results.

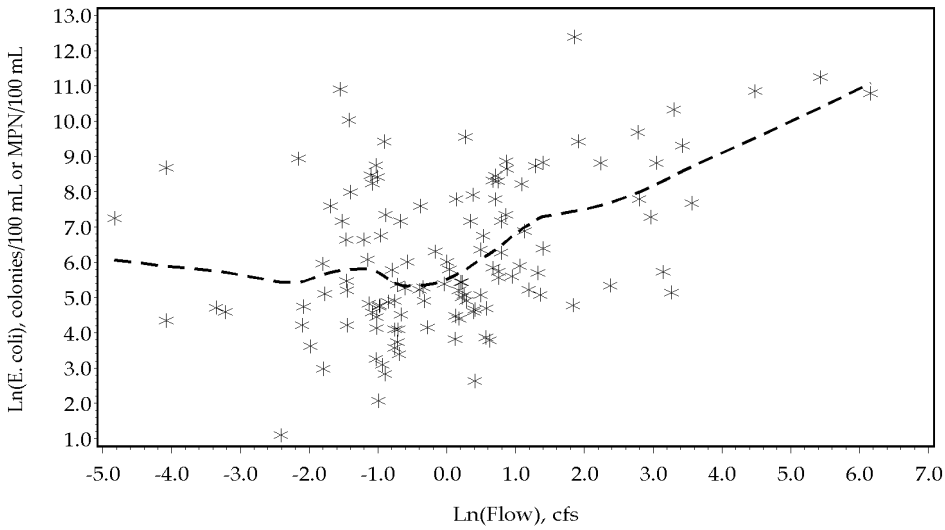
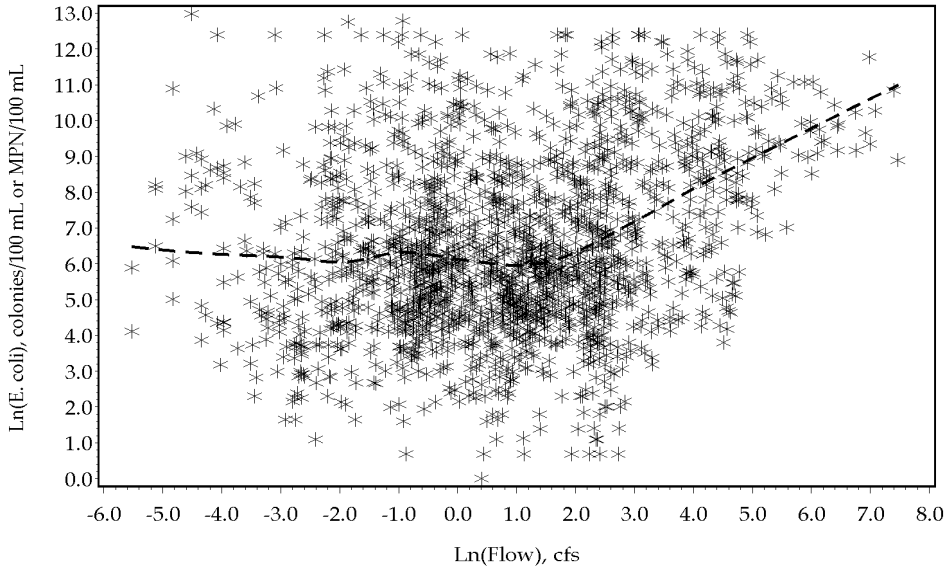


**Figure 15** Relationship of bacteria concentration to flow for all sites combined. Dashed line represents LOWESS regression results.




# Comparisons with Land Use

To evaluate the association of water quality concentrations with land use, correlation analysis was performed using geometric mean concentrations from storm events with land-use characteristics. The correlation analysis indicated that the percent WAFs in the drainage above sampling sites had a significant positive correlation with EMCs, while the percent wood/range had a significant negative correlation (Table 9). The percent land associated with urban and impervious surfaces also generally indicated significant positive correlations with water quality, but these correlations should be interpreted carefully. The percent land area associated with urban and impervious surfaces was generally less than five percent in any given drainage area, thus, representing a relatively small percent of the overall land use. While most correlations with percent pasture were not significant at $\alpha$=0.05, a significant negative correlation of percent pasture with total-P and *E. coli* was shown. A significant positive correlation was indicated for $NO_2$-N+$NO_3$-N with the percent cropland. Overall most significant correlations had correlation coefficients of less than 0.70 indicating that the correlation represented less than 50 percent of the variability in the data.

**Table 9** Correlation of land characteristics with median EMCs from storm events. 'r' represents the correlation coefficient and 'p' represents the p-value or level of significance of the correlation. Bolded values represent significant correlations at α=0.05.

| | | NH3-N (mg/L) | NO2-N +NO3-N (mg/L) | TKN (mg/L) | PO4-P (mg/L) | Total-P (mg/L) | TSS (mg/L) | *E. coli*[a] (MPN/ 100ml) |
|---|---|---|---|---|---|---|---|---|
| WAFs (%) | r | **0.83** | **0.54** | **0.90** | **0.70** | **0.85** | **0.78** | **0.91** |
| | p | **<0.0001** | **0.0200** | **<0.0001** | **0.0014** | **<0.0001** | **0.0002** | **<0.0001** |
| Wood/Range (%) | r | **-0.68** | **-0.65** | **-0.73** | **-0.50** | **-0.62** | **-0.61** | **-0.64** |
| | p | **0.0019** | **0.0033** | **0.0006** | **0.0343** | **0.0058** | **0.0075** | **0.0101** |
| Pasture (%) | r | -0.46 | -0.16 | -0.45 | -0.43 | **-0.50** | -0.44 | -0.04 |
| | p | 0.0519 | 0.5158 | 0.0604 | 0.0732 | **0.0345** | 0.0670 | 0.8989 |
| Cropland (%) | r | 0.40 | **0.58** | 0.35 | 0.14 | 0.22 | 0.36 | 0.06 |
| | p | 0.0982 | **0.0110** | 0.1578 | 0.5703 | 0.3755 | 0.1402 | 0.8232 |
| Urban (%) | r | **0.61** | **0.60** | **0.52** | **0.58** | **0.59** | 0.41 | 0.12 |
| | p | **0.0075** | **0.0082** | **0.0281** | **0.0122** | **0.0096** | 0.0941 | 0.6694 |
| Intensive Ag. (%) | r | **0.87** | **0.66** | **0.92** | **0.67** | **0.83** | **0.81** | **0.82** |
| | p | **<0.0001** | **0.0026** | **<0.0001** | **0.0022** | **<0.0001** | **<0.0001** | **0.0002** |
| Non-Intensive Ag. (%) | r | **-0.87** | **-0.68** | **-0.91** | **-0.69** | **-0.84** | **-0.79** | **-0.80** |
| | p | **<0.0001** | **0.0018** | **<0.0001** | **0.0014** | **<0.0001** | **<0.0001** | **0.0004** |
| Total Area (ha) | r | **-0.56** | -0.23 | **-0.56** | -0.44 | **-0.52** | **-0.48** | 0.41 |
| | p | **0.0154** | 0.3521 | **0.0149** | 0.0694 | **0.0263** | **0.0436** | 0.1260 |

a. Geometric mean *E. coli* values were obtained from grab samples collected during storm events and used for comparison with land-use characteristics rather than the median of EMCs.

To evaluate the impact of land use categories associated with more intensive agriculture versus less intensive practices, the percent land area associated with wood/range and pasture were added together to represent non-intensive agriculture and the percent land area associated with WAFs and cropland were added together to represent more intensive agriculture. The correlation coefficients indicated a trade-off between intensive and non-intensive agriculture with regard to storm water quality (Table 9). In general, drainage areas above sampling sites with a large portion of land associated with intensive agriculture had less associated with non-intensive agriculture. While not a major explanatory variable, there was also generally a significant negative correlation between water quality and the size of the drainage area. That is as drainage area increased, water quality concentrations decreased.

# Trend Analysis

Trend analyses on volume-weighted storm samples collected from 2001 through 2007 indicated few significant trends in water quality (Tables 10-15). Downward trends in $PO_4$-P were indicated at stations GM060 and SC020 and increasing trends were indicated at stations LD040 and SF085 (Table 10). For total-P, downward trends were indicated at stations GB025, GM060, NF020, and SC020 (Table 11). Decreasing trends in $NH_3$-N were indicated at stations DB035, LG060, NF020, and SC020 (Table 12). Decreasing trends in $NO_2$-N+$NO_3$-N were detected at stations GB040, GM060, IC020, NF020, SC020, and SP020 (Table 13). Decreasing trends in TKN were indicated at stations AL020, GM060, HY060, IC020, NF020, and SC020 (Table 14). No significant trends in TSS were indicated at any of the stations (Table 15).

**Table 10** 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.

| Station | Period Evaluated | Kendall Test Statistic | p-value | Slope (% change/ yr) |
|---|---|---|---|---|
| AL020 | Sep 2001-Dec 2007 | -0.021 | 0.8401 | |
| DB035 | Feb 2002-Dec 2007 | 0.092 | 0.3734 | |
| DC040 | May 2001-Nov 2007 | 0.058 | 0.5310 | |
| GB020 | Jan 2001-Jun 2007 | -0.048 | 0.7212 | |
| GB025 | Jan 2001-May 2007 | -0.112 | 0.3067 | |
| GB040 | Jan 2001-May 2007 | -0.023 | 0.8342 | |
| GC045 | May 2001-Sep 2007 | -0.095 | 0.4216 | |
| GM060 | Aug 2001-Dec 2007 | -0.373 | 0.0010** | -3.22 |
| HY060 | May 2001-Nov 2007 | 0.015 | 0.8980 | |
| IC020 | May 2001-Sep 2007 | -0.121 | 0.2403 | |
| LD040 | Aug 2001-Nov 2007 | 0.215 | 0.0461* | 0.50 |
| LG060 | Jul 2001-Nov 2007 | -0.226 | 0.0719 | |
| NF009 | Jan 2001-Nov 2007 | -0.068 | 0.5367 | |
| NF020 | Feb 2001-Sep 2007 | 0.033 | 0.7615 | |
| NF050 | May 2001-Nov 2007 | 0.137 | 0.1866 | |
| SC020 | May 2001-Dec 2007 | -0.223 | 0.0277* | -1.41 |
| SF085 | May 2001-Dec 2007 | 0.220 | 0.0063** | 0.66 |
| SP020 | May 2001-Nov 2007 | -0.030 | 0.7764 | |

**Table 11** 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.

| Station | Period Evaluated | Kendall Test Statistic | p-value | Slope (% change/ yr) |
|---|---|---|---|---|
| AL020 | Sep 2001-Dec 2007 | -0.106 | 0.2958 | |
| DB035 | Feb 2002-Dec 2007 | -0.092 | 0.3735 | |
| DC040 | May 2001-Nov 2007 | 0.032 | 0.7307 | |
| GB020 | Jan 2001-Jun 2007 | -0.103 | 0.4325 | |
| GB025 | Jan 2001-May 2007 | -0.271 | 0.0131* | -0.84 |
| GB040 | Jan 2001-May 2007 | -0.111 | 0.3001 | |
| GC045 | May 2001-Sep 2007 | -0.121 | 0.3070 | |
| GM060 | Aug 2001-Dec 2007 | -0.377 | 0.0009** | -2.14 |
| HY060 | May 2001-Nov 2007 | 0.018 | 0.8796 | |
| IC020 | May 2001-Sep 2007 | -0.173 | 0.0919 | |
| LD040 | Aug 2001-Nov 2007 | 0.010 | 0.3625 | |
| LG060 | Jul 2001-Nov 2007 | -0.081 | 0.5271 | |
| NF009 | Jan 2001-Nov 2007 | -0.004 | 0.9821 | |
| NF020 | Feb 2001-Sep 2007 | -0.263 | 0.0135* | -0.72 |
| NF050 | May 2001-Nov 2007 | 0.030 | 0.777 | |
| SC020 | May 2001-Dec 2007 | -0.219 | 0.0304* | -0.93 |
| SF085 | May 2001-Dec 2007 | 0.123 | 0.1269 | |
| SP020 | May 2001-Nov 2007 | -0.183 | 0.0751 | |

**Table 12** 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-Dec 2007 | 0.007 | 0.9489 | |
| DB035 | Feb 2002-Dec 2007 | -0.218 | 0.0331* | -1.04 |
| DC040 | May 2001-Nov 2007 | 0.050 | 0.5866 | |
| GB020 | Jan 2001-Jun 2007 | 0.000 | 1.000 | |
| GB025 | Jan 2001-May 2007 | -0.077 | 0.4862 | |
| GB040 | Jan 2001-May 2007 | -0.125 | 0.2412 | |
| GC045 | May 2001-Sep 2007 | -0.194 | 0.0993 | |
| GM060 | Aug 2001-Dec 2007 | -0.030 | 0.8015 | |
| HY060 | May 2001-Nov 2007 | -0.124 | 0.2633 | |
| IC020 | May 2001-Sep 2007 | -0.200 | 0.0511 | |
| LD040 | Aug 2001-Nov 2007 | 0.095 | 0.3737 | |
| LG060 | Jul 2001-Nov 2007 | -0.278 | 0.0263* | -1.82 |
| NF009 | Jan 2001-Nov 2007 | -0.065 | 0.5592 | |
| NF020 | Feb 2001-Sep 2007 | -0.245 | 0.0213* | -1.49 |
| NF050 | May 2001-Nov 2007 | -0.123 | 0.2366 | |
| SC020 | May 2001-Dec 2007 | -0.393 | 0.0001** | -2.37 |
| SF085 | May 2001-Dec 2007 | 0.0610 | 0.4512 | |
| SP020 | May 2001-Nov 2007 | -0.109 | 0.2890 | |

**Table 13** 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-Dec 2007 | 0.062 | 0.5450 | |
| DB035 | Feb 2002-Dec 2007 | -0.066 | 0.5258 | |
| DC040 | May 2001-Nov 2007 | -0.049 | 0.5961 | |
| GB020 | Jan 2001-Jun 2007 | -0.062 | 0.6427 | |
| GB025 | Jan 2001-May 2007 | -0.200 | 0.0671 | |
| GB040 | Jan 2001-May 2007 | -0.234 | 0.0280* | -1.70 |
| GC045 | May 2001-Sep 2007 | 0.041 | 0.7335 | |
| GM060 | Aug 2001-Dec 2007 | -0.294 | 0.0096** | -2.15 |
| HY060 | May 2001-Nov 2007 | -0.085 | 0.4489 | |
| IC020 | May 2001-Sep 2007 | -0.219 | 0.0324* | -0.91 |
| LD040 | Aug 2001-Nov 2007 | 0.103 | 0.3356 | |
| LG060 | Jul 2001-Nov 2007 | -0.214 | 0.0886 | |
| NF009 | Jan 2001-Nov 2007 | 0.093 | 0.3996 | |
| NF020 | Feb 2001-Sep 2007 | -0.298 | 0.0050** | -1.27 |
| NF050 | May 2001-Nov 2007 | -0.103 | 0.3232 | |
| SC020 | May 2001-Dec 2007 | -0.253 | 0.0126* | -1.19 |
| SF085 | May 2001-Dec 2007 | 0.032 | 0.6974 | |
| SP020 | May 2001-Nov 2007 | -0.316 | 0.0020** | -1.99 |

**Table 14** 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-Dec 2007 | -0.203 | 0.046* | -0.54 |
| DB035 | Feb 2002-Dec 2007 | -0.182 | 0.0766 | |
| DC040 | May 2001-Nov 2007 | -0.074 | 0.4206 | |
| GB020 | Jan 2001-Jun 2007 | -0.083 | 0.5323 | |
| GB025 | Jan 2001-May 2007 | -0.161 | 0.1412 | |
| GB040 | Jan 2001-May 2007 | -0.147 | 0.1672 | |
| GC045 | May 2001-Sep 2007 | -0.171 | 0.1450 | |
| GM060 | Aug 2001-Dec 2007 | -0.371 | 0.0011** | -1.26 |
| HY060 | May 2001-Nov 2007 | -0.240 | 0.0302* | -0.75 |
| IC020 | May 2001-Sep 2007 | -0.238 | 0.0204* | -0.46 |
| LD040 | Aug 2001-Nov 2007 | 0.062 | 0.5649 | |
| LG060 | Jul 2001-Nov 2007 | -0.169 | 0.1783 | |
| NF009 | Jan 2001-Nov 2007 | 0.043 | 0.7025 | |
| NF020 | Feb 2001-Sep 2007 | -0.266 | 0.0124* | -0.90 |
| NF050 | May 2001-Nov 2007 | -0.152 | 0.1449 | |
| SC020 | May 2001-Dec 2007 | -0.360 | 0.0003** | -1.50 |
| SF085 | May 2001-Dec 2007 | -0.031 | 0.7010 | |
| SP020 | May 2001-Nov 2007 | -0.044 | 0.6701 | |

**Table 15** 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-Dec 2007 | -0.024 | 0.8187 | |
| DB035 | Feb 2002-Dec 2007 | -0.186 | 0.0691 | |
| DC040 | May 2001-Nov 2007 | -0.008 | 0.9396 | |
| GB020 | Jan 2001-Jun 2007 | -0.172 | 0.1868 | |
| GB025 | Jan 2001-May 2007 | -0.095 | 0.3871 | |
| GB040 | Jan 2001-May 2007 | -0.145 | 0.1737 | |
| GC045 | May 2001-Sep 2007 | -0.041 | 0.7335 | |
| GM060 | Aug 2001-Dec 2007 | -0.186 | 0.1022 | |
| HY060 | May 2001-Nov 2007 | -0.027 | 0.8157 | |
| IC020 | May 2001-Sep 2007 | 0.030 | 0.7764 | |
| LD040 | Aug 2001-Nov 2007 | -0.185 | 0.0823 | |
| LG060 | Jul 2001-Nov 2007 | -0.137 | 0.2773 | |
| NF009 | Jan 2001-Nov 2007 | 0.037 | 0.7446 | |
| NF020 | Feb 2001-Sep 2007 | -0.198 | 0.0625 | |
| NF050 | May 2001-Nov 2007 | -0.103 | 0.3232 | |
| SC020 | May 2001-Dec 2007 | -0.184 | 0.0694 | |
| SF085 | May 2001-Dec 2007 | 0.101 | 0.2098 | |
| SP020 | May 2001-Nov 2007 | -0.179 | 0.0866 | |

Although decreasing trends in $PO_4$-P were significant at only a relatively few sites (Table 10), there did appear to be a decreasing pattern at several sites from 2001 to 2005 with a increase often seen in 2006 and a decrease again in 2007 (see Figure 16 as an example). Even at site GM060 where a significant decreasing trend in $PO_4$-P was indicated, slightly higher concentrations were noted in 2006 (Figure 17). It is unclear exactly why this increase in $PO_4$-P concentrations occurred in 2006, but hydrologically 2006 was a relatively dry year, and at many sites, only a very few storm events were monitored (Table 16). Also of note, many of the sites were not installed until April or May 2001, so the storms monitored in 2001 are not indicative of the number of total storms that occurred that year.

**Figure 16** Box and whisker plots of storm $PO_4$-P concentrations at AL020 by year. Data transformed using a natural log transformation and volume adjusted for varying size storm events.

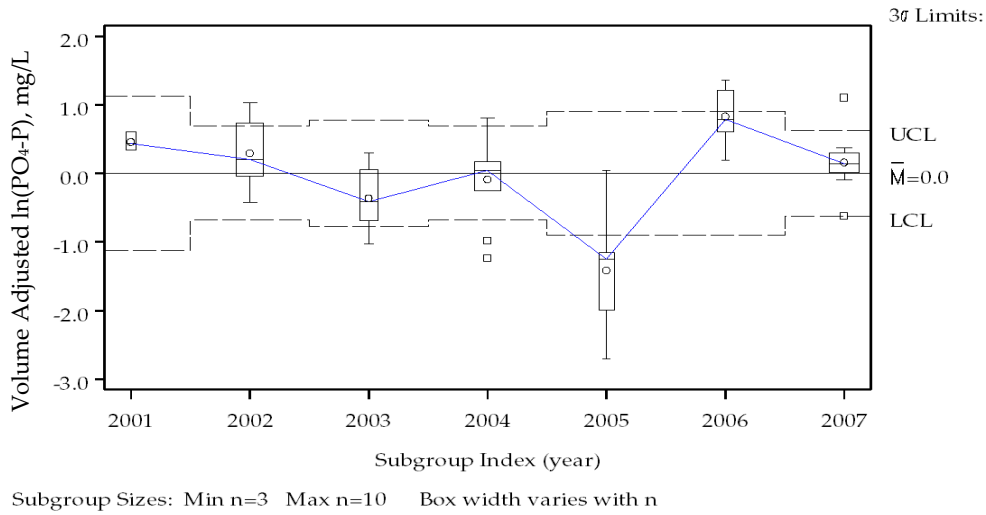



**Figure 17** Box and whisker plots of storm $PO_4$-P concentrations at GM060 by year. Data transformed using a natural log transformation and volume adjusted for varying size storm events.

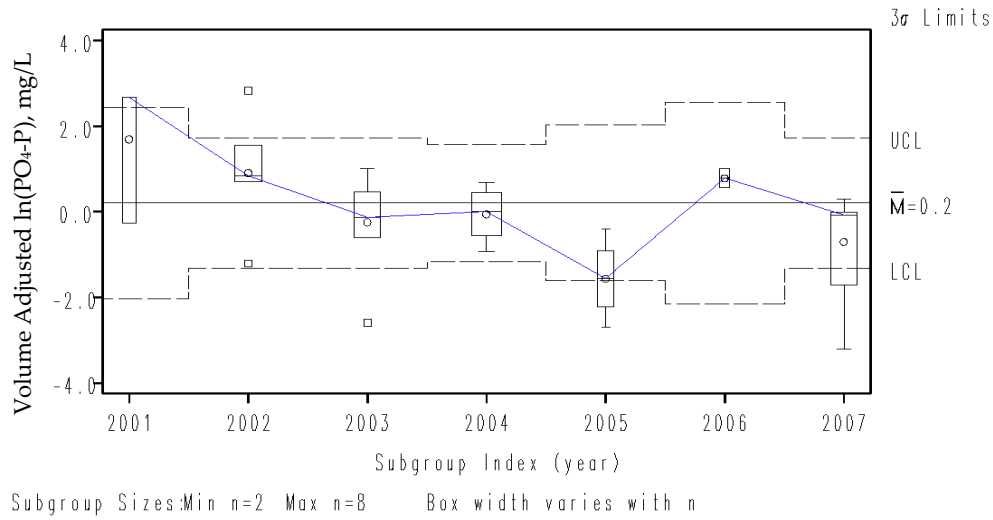


**Table 16** Number of storm events for each site per year.

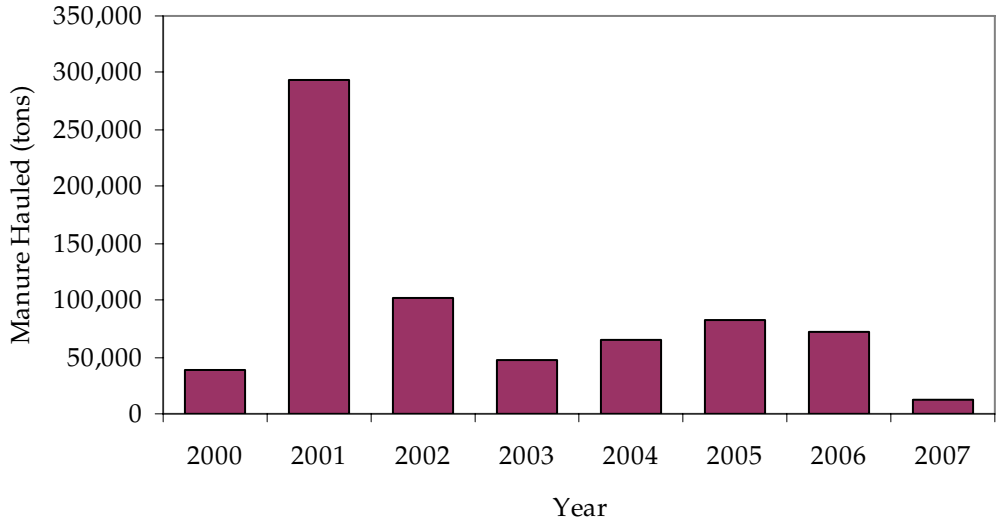
| Site | 2001[a] | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | Average per site |
|---|---|---|---|---|---|---|---|---|
| AL020 | 3 | 15 | 15 | 12 | 8 | 5 | 20 | 11 |
| DB035 | NA[b] | 19 | 18 | 17 | 7 | 5 | 18 | 14 |
| DC040 | 10 | 19 | 10 | 14 | 9 | 9 | 27 | 14 |
| GB020 | 6 | 9 | 2 | 10 | 5 | 5 | 10 | 7 |
| GB025 | 9 | 14 | 5 | 15 | 4 | 8 | 2 | 8 |
| GB040 | 9 | 14 | 9 | 16 | 9 | 6 | 2 | 9 |
| GC045 | 4 | 14 | 11 | 12 | 7 | 2 | 15 | 9 |
| GM060 | 3 | 11 | 12 | 16 | 9 | 2 | 16 | 10 |
| HY060 | 2 | 9 | 12 | 22 | 9 | 2 | 16 | 10 |
| IC020 | 4 | 19 | 8 | 13 | 9 | 7 | 18 | 11 |
| LD040 | 3 | 9 | 6 | 12 | 5 | 8 | 19 | 9 |
| LG060 | 2 | 13 | 7 | 7 | 1 | 3 | 13 | 7 |
| NF009 | 8 | 11 | 7 | 11 | 4 | 8 | 15 | 9 |
| NF020 | 9 | 17 | 8 | 15 | 5 | 4 | 16 | 11 |
| NF050 | 7 | 13 | 13 | 12 | 4 | 8 | 18 | 11 |
| SC020 | 2 | 9 | 11 | 17 | 10 | 15 | 17 | 12 |
| SF085 | 11 | 25 | 24 | 24 | 19 | 15 | 24 | 20 |
| SP020 | 7 | 16 | 11 | 19 | 8 | 2 | 18 | 12 |
| Average per year | 6 | 14 | 11 | 15 | 7 | 6 | 16 | 11 |

a. Most sampling sites were not installed until April or May 2001, so the number of storm events monitored is not representative of storm events throughout the entire year.
b. NA indicates not applicable. Site DB035 was not installed until 2002.

# Manure Hauled to Composting Facilities

Although short-term water quality trends did not indicate strong decreases from 2001 through 2007, it was anticipated that nonpoint source nutrient contributions from dairy waste application fields would decrease with implementation of the manure composting program compared to a pre-implementation time period. With the initiation of the manure composting program, over 700,000 tons of dairy manure were hauled-off to composting facilities from within the North Bosque River watershed between November 2000 and February 2007. The greatest manure haul-off occurred in 2001 with a notable drop in 2003 (Figure 18). The amount of manure hauled-off in 2000 represents only the last two months of the year. The amount of manure hauled-off in 2001 was about five times the manure hauled in 2004. The relatively large delivery of manure to composting facilities in 2001 was in part related to stockpiling of manure on dairies in anticipation of the project. As a result, manure hauled in 2001 was greater than the total manure generated that year. The specific reasons for the decrease in manure hauled in 2003 as compared to 2002 and lower levels continuing in 2004 through 2006 are unknown, although it is speculated that other programs may be competing for manure (TIAER, 2003).

**Figure 18** Manure hauled-off from the North Bosque River watershed to composting facilities between November 2000 and February 2007.




In February 2007, the Dairy Manure Export Support (DMES) Project ended and the amount of manure hauled to composting facilities was no longer tracked and reported. Of the seven composting facilities known to have accepted manure as part of the DMES project, six of the facilities were still in operation as of March 2008. These six composting facilities are still receiving manure from dairy operations. Although the actual amount of manure being transported to composting facilities is no longer being tracked, a review of pending permits for several dairy operations in the watershed indicated that most dairy facilities plan to use composting as an option in management of their solid manure.

Manure hauled by year was also evaluated by microwatershed (Figure 19). The most manure hauled occurred in the GC045 drainage area on Greens Creek and from above the HY060 drainage area on Honey Creek. The GC045 and HY060 microwatersheds represent two of the larger watershed areas of the sites evaluated (Table 3), so not only the total amount hauled needs to be taken into account, but also the drainage area and the number of dairy cows to more accurately assess the potential impact of the manure composting program on stream water quality.

In order to relate the amount of manure exported from microwatersheds above sampling sites to changes in water quality, the amount of manure hauled-off was normalized by estimated cow numbers and drainage area (Figure 20). Dairy cow numbers were based on an average of inspected values from 2000 through 2007. The most manure hauled per cow and unit drainage area occurred in microwatersheds above sites NF020, GB020, and GB040. Of note, the same dairy operations were associated with GB020 and GB025, but the drainage area above GB025 is much larger. Both GB020 and GB025 were included in the monitoring program due to landowner requests, although the drainage area of GB025 includes more of the runoff associated with the waste application fields for these dairy operations.

**Figure 19** Manure hauled-off to composting facilities from within microwatersheds above sampling sites within the North Bosque watershed between November 2000 and December 2007. Note: GB020 not shown, because values are the same as for GB025.

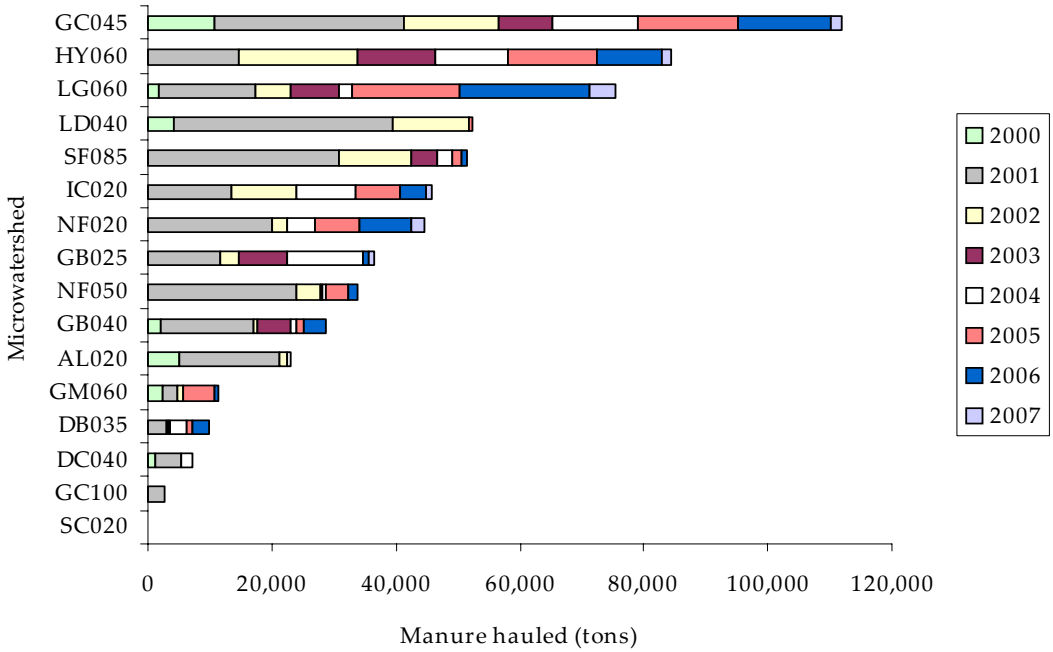
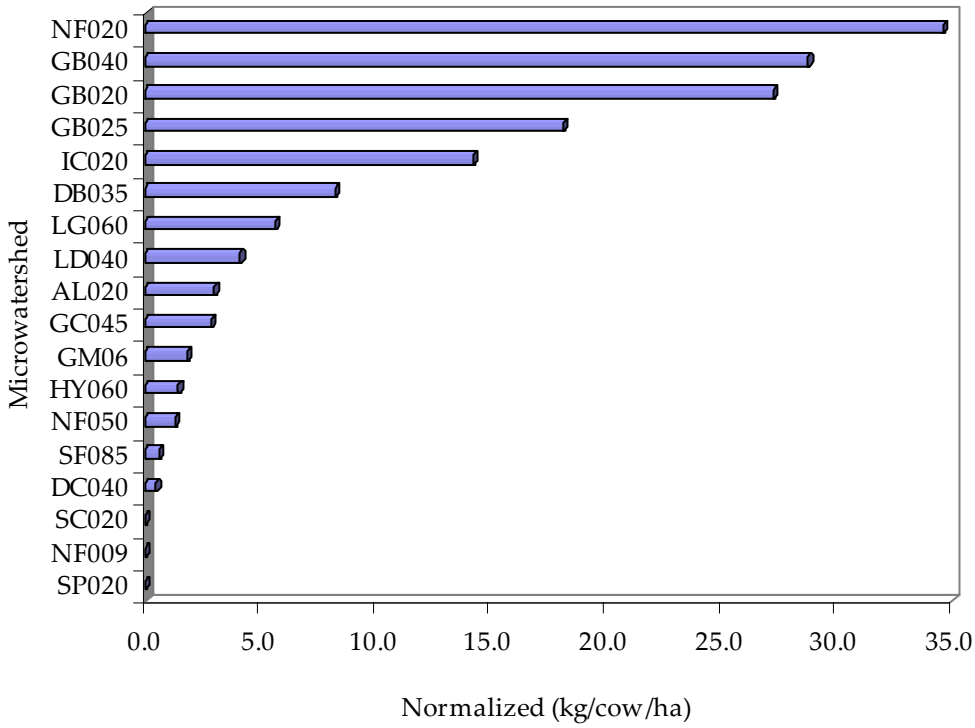



**Figure 20** Manure hauled normalized by drainage area and cow number for microwatersheds above sampling sites.



It was expected that the sampling sites with the greatest manure export per cow and unit drainage area would show the greatest improvement in water quality, especially with respect to $PO_4$-P. Although there are three dairies in the watershed above site SC020 and a few waste application fields in the drainage above site NF009, none of these dairies had manure hauled to composting facilities. The drainage area above site SP020 contains no dairy operations, and, thus, had no manure haul-off.

# Water Quality Before/After Results

To look at changes before and after implementation of the manure composting program, six sites (GB025, GB040, IC020, NF020, SC020, and SP020) with long-term storm data were evaluated (see Table 2). Summary statistics of the flow adjusted and natural log (ln) transformed data that have been back transformed into the original units are presented in Table 17. Because the standard deviation of log transformed data is not symmetrical about the mean when back transformed, an upper and lower bound is presented representing the mean plus and minus one standard error. Of note for site SC020, median values from the untransformed data are presented, because the flow-concentration relationship changed between the "before" and "after" periods making flow-adjustment inappropriate. These statistics can be used to generally compare water quality at a site between the two periods. Results obtained from step trend analyses on the flow adjusted and natural log transformed data are presented in Table 18.

Comparing EMCs within a monitoring period, the summary statistics were generally reflective of the major land uses in the drainage area above each site (Table 3). Sampling sites with drainage areas containing a large percentage of land area comprised of dairy waste application fields, such as GB025 and NF020, consistently showed the highest $PO_4$-P and total P concentrations. Whereas sampling sites with few or no dairies in their drainage area, such as site SP020, indicated the lowest $PO_4$-P and total P EMCs. The general pattern shown for $PO_4$-P and total P concentrations also occurred for TKN and to a lesser degree for $NH_3$-N, $NO_2$-N+$NO_3$-N, and TSS (Table 18). Although site GB040 has a moderately high percentage of dairy waste application fields in its drainage area (30 percent), this site has some of the highest average $NO_2$-N+$NO_3$-N and TSS concentrations. Site GB040 does have a history of cows watering from the creek. The direct impact from cows watering in the creek near GB040 is probably a factor in the relatively high $NO_2$-N+$NO_3$-N and TSS concentrations found at this site.

In comparing changes in EMCs between the "before" and "after" manure-composting periods using ANCOVA, data were transformed using the natural log. Estimated means from the ANCOVA were flow adjusted based on the average flow for each event. The ANCOVA evaluates differences among treatment level means (before and after periods) that would occur if all concentrations had the same streamflow (Keppel, 1991). Of note, estimated mean concentrations for the before period vary slightly from previous reports (e.g., McFarland and Millican, 2006), because flow in the after period has changed with the monitoring of additional storm events through 2007 (see Ott, 1984).

**Table 17** Storm event summary statistics for microwatershed sampling sites.
Before and after refer to storm events monitored "before" and "after" the initiation of the manure composting program. Data were flow-adjusted and transformed using a natural log transformation and then back transformed into original units.

| Site | Attribute | Number of Events | | Mean[a] | | Lower Standard Error Bound | | Upper Standard Error Bound | |
|---|---|---|---|---|---|---|---|---|---|
| | | Before | After | Before | After | Before | After | Before | After |
| GB025 | $PO_4$-P (mg/L) | 36 | 59 | 1.26 | 0.923 | 1.14 | 0.85 | 1.40 | 1.00 |
| | Total P (mg/L) | 36 | 59 | 3.25 | 2.85 | 3.05 | 2.68 | 3.51 | 3.03 |
| | TSS (mg/L) | 35 | 59 | 982 | 894 | 779 | 751 | 1240 | 1070 |
| | $NO_2$-N+$NO_3$-N (mg/L) | 36 | 59 | 1.11 | 1.05 | 0.97 | 0.94 | 1.28 | 1.17 |
| | $NH_3$-N (mg/L) | 36 | 59 | 0.27 | 0.33 | 0.23 | 0.29 | 0.32 | 0.37 |
| | TKN (mg/L) | 36 | 59 | 7.86 | 7.64 | 7.13 | 7.09 | 8.66 | 8.23 |
| GB040 | $PO_4$-P (mg/L) | 28 | 66 | 1.15 | 0.875 | 1.05 | 0.821 | 1.27 | 0.932 |
| | Total P (mg/L) | 28 | 66 | 2.60 | 2.24 | 2.32 | 2.08 | 2.93 | 2.41 |
| | TSS (mg/L) | 28 | 66 | 567 | 624 | 440 | 531 | 729 | 734 |
| | $NO_2$-N+$NO_3$-N (mg/L) | 28 | 66 | 3.22 | 2.64 | 2.57 | 2.28 | 4.04 | 3.06 |
| | $NH_3$-N (mg/L) | 28 | 66 | 0.65 | 0.40 | 0.55 | 0.36 | 0.76 | 0.44 |
| | TKN (mg/L) | 28 | 66 | 7.58 | 6.25 | 6.68 | 5.77 | 8.59 | 6.78 |
| IC020 | $PO_4$-P (mg/L) | 60 | 78 | 0.518 | 0.499 | 0.471 | 0.459 | 0.570 | 0.542 |
| | Total P (mg/L) | 60 | 78 | 0.92 | 1.12 | 0.86 | 1.05 | 0.98 | 1.19 |
| | TSS (mg/L) | 60 | 78 | 122 | 245 | 106 | 219 | 139 | 276 |
| | $NO_2$-N+$NO_3$-N (mg/L) | 60 | 78 | 0.64 | 0.96 | 0.56 | 0.86 | 0.73 | 1.08 |
| | $NH_3$-N (mg/L) | 60 | 78 | 0.10 | 0.15 | 0.09 | 0.13 | 0.12 | 0.17 |
| | TKN (mg/L) | 60 | 78 | 2.64 | 3.39 | 2.48 | 3.21 | 2.80 | 3.57 |
| NF020 | $PO_4$-P (mg/L) | 81 | 75 | 0.759 | 0.701 | 0.694 | 0.638 | 0.830 | 0.769 |
| | Total P (mg/L) | 81 | 75 | 1.82 | 1.75 | 1.71 | 1.64 | 1.93 | 1.86 |
| | TSS (mg/L) | 81 | 75 | 584 | 349 | 507 | 301 | 673 | 405 |
| | $NO_2$-N+$NO_3$-N (mg/L) | 81 | 75 | 1.07 | 0.94 | 0.99 | 0.87 | 1.15 | 1.01 |
| | $NH_3$-N (mg/L) | 81 | 75 | 0.25 | 0.19 | 0.22 | 0.17 | 0.28 | 0.22 |
| | TKN (mg/L) | 80 | 75 | 4.62 | 4.72 | 4.34 | 4.42 | 4.93 | 5.05 |
| SC020 | $PO_4$-P (mg/L) | 52 | 81 | 0.140 | 0.110 | na[b] | na | na | na |
| | Total P (mg/L) | 52 | 81 | 0.34 | 0.36 | na | na | na | na |
| | TSS (mg/L) | 52 | 81 | 64 | 87 | na | na | na | na |
| | $NO_2$-N+$NO_3$-N (mg/L) | 52 | 81 | 0.39 | 0.38 | na | na | na | na |
| | $NH_3$-N (mg/L) | 52 | 81 | 0.10 | 0.06 | na | na | na | na |
| | TKN (mg/L) | 52 | 81 | 1.37 | 1.36 | na | na | na | na |
| SP020 | $PO_4$-P (mg/L) | 61 | 81 | 0.022 | 0.015 | 0.020 | 0.013 | 0.025 | 0.016 |
| | Total P (mg/L) | 61 | 81 | 0.11 | 0.12 | 0.10 | 0.11 | 0.12 | 0.13 |
| | TSS (mg/L) | 61 | 81 | 18.4 | 32.9 | 16 | 28 | 22 | 38 |
| | $NO_2$-N+$NO_3$-N (mg/L) | 61 | 81 | 0.06 | 0.06 | 0.05 | 0.05 | 0.07 | 0.07 |
| | $NH_3$-N (mg/L) | 61 | 81 | 0.07 | 0.03 | 0.06 | 0.03 | 0.07 | 0.03 |
| | TKN (mg/L) | 61 | 81 | 0.94 | 0.59 | 0.87 | 0.55 | 1.01 | 0.63 |

a. Median rather than mean values are presented for SC020 that were not adjusted for flow, because the flow-concentration relationship for site SC020 changed between the "before" and "after" monitoring periods. The data for SC020 were also not natural log transformed, because the "before" and "after" analysis was evaluated on median values using the Wilcoxon nonparametric test.
b. na indicates not available. A standard error bound is not presented for SC020, because a standard error on a median is very difficult to accurately compute for non-normal distributions.

Statistically significant reductions in $PO_4$-P concentrations were observed at sites GB025, GB040, and SP020 for both the ANCOVA and WRS results (Table 18). These reductions were estimated to be 27 percent of the "before" concentration for site GB025, 24 percent for site GB040, and 32 percent for site SP020 (Table 19). At site NF020, reductions in $PO_4$-P were significant based only on the WRS test. Sites GB025,

GB040, and NF020 are highly impacted by dairy operations (Table 3), and these operations have had a relatively high level of participation in the manure composting program.

**Table 18** P-values from analysis of covariance (ANCOVA) and Wilcoxon Rank Sum (WRS) comparing event mean concentrations "before" and "after" the start of the manure haul-off program. Arrows indicate significant increases and decreases (alpha=0.1) in storm water quality from "before" to "after" implementation of the manure composting program.

| Site | Analysis | $PO_4$-P | Total P | TSS | $NO_2$-N +$NO_3$-N | $NH_3$-N | TKN |
|---|---|---|---|---|---|---|---|
| GB025 | ANCOVA | 0.0254 (↓) | 0.2121 | 0.7564 | 0.7588 | 0.4087 | 0.8244 |
| | WRS | 0.0220 (↓) | 0.1602 | 0.3029 | 0.4557 | 0.0967 (↑) | 0.3780 |
| GB040 | ANCOVA | 0.0216 (↓) | 0.2852 | 0.7506 | 0.4727 | 0.0184 (↓) | 0.2075 |
| | WRS | 0.0020 (↓) | 0.0283 (↓) | 0.2912 | 0.1576 | 0.0294 (↓) | 0.0173 (↓) |
| IC020 | ANCOVA | 0.7662 | 0.0386 (↑) | 0.0002 (↑) | 0.0227 (↑) | 0.0253 (↑) | 0.0030 (↑) |
| | WRS | 0.3859 | 0.0042 (↑) | 0.0009 (↑) | 0.0034 (↑) | 0.0252 (↑) | 0.0027 (↑) |
| NF020 | ANCOVA | 0.5388 | 0.6666 | 0.0131 (↓) | 0.2208 | 0.1803 | 0.8092 |
| | WRS | 0.0279 (↓) | 0.0339 (↓) | 0.0061 (↓) | 0.0464 (↓) | 0.0449 (↓) | 0.1410 |
| SC020 | ANCOVA | na[a] | na | na | na | na | na |
| | WRS[b] | 0.4472 | 0.4770 | 0.0492 (↑) | 0.1776 | 0.0389 (↓) | 0.1911 |
| SP020 | ANCOVA | 0.0027 (↓) | 0.2982 | 0.0130 (↑) | 0.8905 | <0.0001 (↓) | 0.3646 |
| | WRS | <0.0001 (↓) | 0.4119 | 0.0139 (↑) | 0.4984 | <0.0001 (↓) | 0.4475 |

a. na indicates not applicable due to changes in the flow-concentration relationship at SC020 between the "before" and "after" periods violating assumptions for the ANCOVA procedure.
b. EMCs at SC020 were not flow-adjusted prior to conducting the analysis, because the flow-concentration relationship had changed between the "before" and "after" periods due to the construction of a small dam upstream of the site.

**Table 19** Estimated change in flow adjusted $PO_4$-P concentrations "before" and "after" implementation of the manure composting program.

| Site | $PO_4$-P (mg/L)[a] | | Absolute Change (mg/L) | Relative Change (%)[b] |
|---|---|---|---|---|
| | Before | After | | |
| GB025 | 1.26 | 0.923 | -0.34 | -26.7 |
| GB040 | 1.15 | 0.875 | -0.28 | -23.9 |
| IC020 | 0.518 | 0.499 | -0.019 | -3.67 |
| NF020 | 0.759 | 0.701 | -0.058 | -7.64 |
| SC020[c] | 0.140 | 0.110 | -0.030 | -21.4 |
| SP020 | 0.022 | 0.015 | -0.007 | -31.8 |

a. Back transformed from natural log into original linear scale as $PO_4\text{-}P_{(Before)} = e_{before}$ and $PO_4\text{-}P_{(After)} = e_{after}$, where "before" and "after" represent EMCs adjusted for the covariate flow (on natural log scale) from the ANCOVA and 'e' is the base of the natural logarithm.
b. Percent change on a linear scale was calculated as $([PO_4\text{-}P_{after} - PO_4\text{-}P_{before}]/PO_4\text{-}P_{before})*100$
c. Percent change for SC020 is presented for flow unadjusted median values rather than flow-adjusted values, because the flow-concentration relationship changed over the analysis period.

Significant reductions in $PO_4$-P indicated at site SP020, a least impacted stream site, were suspected to be a result of improvements in laboratory precision for $PO_4$-P even though data were adjusted for changes in reporting limits for left-censored data. These improvements likely played a role in the detection of significant decreases in the low storm $PO_4$-P concentrations at SP020, although other factors, such as differences in weather and land management patterns between the two time periods

cannot be ruled out. Regardless of the cause, the small absolute decrease at SP020 cannot fully explain the much larger absolute decreases noted at sites GB025 and GB040 (Table 19). Because somewhat different timeframes were evaluated for each site (Table 2), care should be taken in comparing absolute changes for the "before" and "after" periods between sites. Also, the relative change at a site was dependent on the absolute value of the "before" and "after" measurements, so absolute values should be taken into consideration in evaluating these relative changes.

At IC020 and SC020, no statistical differences in the mean or median $PO_4$-P concentrations between the before and after periods were indicated. Of note only the nonparametric Wilcoxon rank sum test was used for data from site SC020, since the flow-concentration relationship significantly changed during the study period for this site violating an assumption of the ANCOVA procedure. Also, EMCs at SC020 were not flow adjusted prior to using the WRS procedure, because of this change in the flow-concentration relationship.

There was no significant difference in EMCs of total P during the two time periods at sites GB025, SC020, and SP020 (Table 18), while a slight but significant decrease in total P was indicated from the WRS test at sites NF020 and GB040. A significant increase in EMCs of total P were indicated from both the ANCOVA and WRS procedures for site IC020.

While decreases in P constituents were expected with the manure-composting program, changes in nitrogen constituents were less certain. Although less manure was applied to the land during the manure composting program, it is likely that producers applied more commercial nitrogen as fertilizer to meet crop needs. Water quality results for $NH_3$-N were mixed (Table 18). Ammonia decreased at sites GB040, NF020, SC020, and SP020 and increased at site IC020. At site IC020, increases in EMCs of $NO_2$-N+$NO_3$-N and TKN were apparent during the period after implementation of the manure-composting program. In addition, increases in TSS were noted at sites IC020 and SP020. It is speculated that changes in land use, such as an increase in cropland farming, would increase concentrations of TSS and related constituents, but without further information detailing specific land use practices within these drainage areas, it is difficult to know why these increases and decreases occurred.

# Discussion

Several factors determine the success of nutrient management practices on stream water quality within a drainage area. These factors include not only the type and number of practices implemented, but the effectiveness of management (Meals, 1992; Bottcher et al., 1995), land-use type (Wang, 2001, Fisher et al., 2000), chemical and hydrologic factors (Sharpley et al. 1999; Moog and Whiting, 2002), length of monitoring (Clausen et al., 1992), and level of farmer participation (Meals, 1992). Most of these factors can be controlled when designing field plot studies, and therefore, a desired result can be obtained within a reasonable period of time. On the watershed or even subwatershed scale, it is often difficult to control these confounding factors, and changes in water quality generally occur more gradually even with fairly abrupt changes in land management. As examples of confounding

factors within the microwatersheds monitored, the inspected number of cows (Figure 21) and the amount of manure hauled per year (Figure 22) varied notably from year to year.

**Figure 21** Temporal variation in estimated cow numbers in microwatersheds above sampling sites.

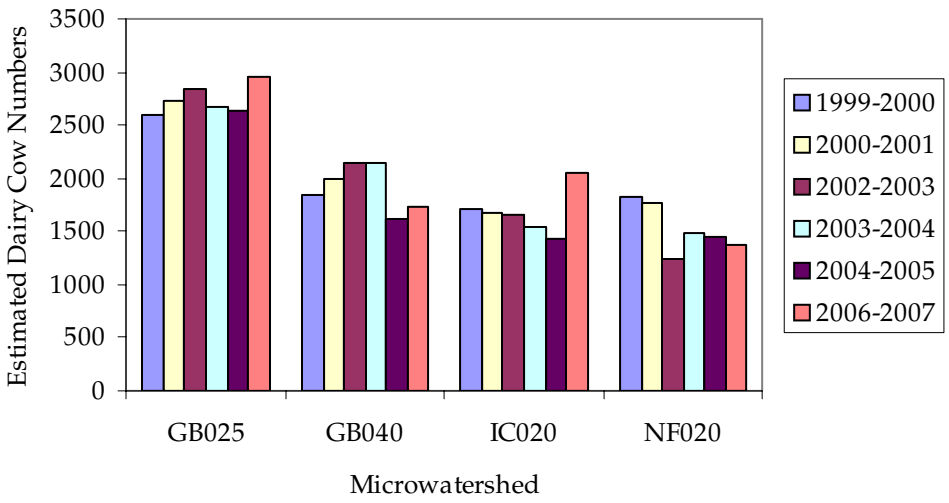
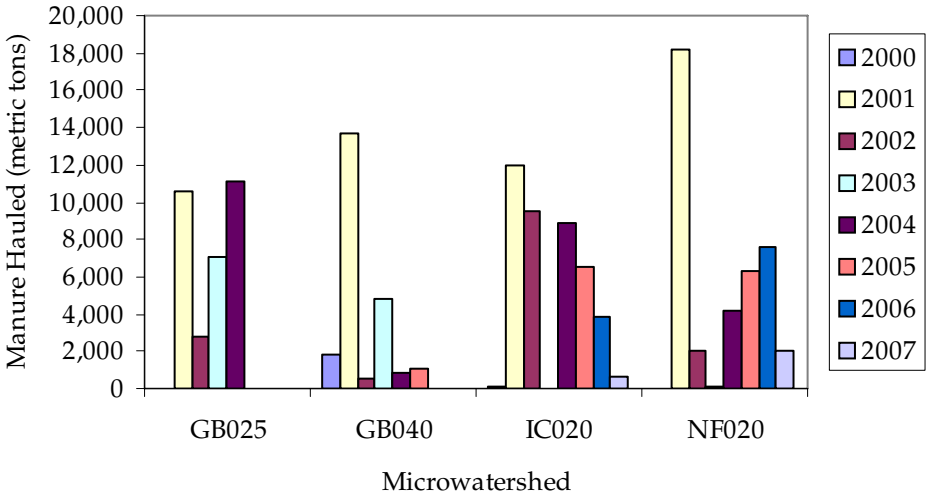



**Figure 22** Temporal changes in manure hauled within microwatersheds above sampling sites. Data for 2000 and 2007 represent only a couple of months in each year rather than full years of haul-off.



Although year to year variations in cow numbers and the amount of manure hauled can confound results, changes in water quality were still noted in association with the composting program. Through DMES, about 700,000 tons of dairy manure were hauled to composting facilities from within the North Bosque River watershed between November 2000 and February 2007. State and federal support of the composting program is now over. Funding for CMIP ended in August 2006 and for the DMES project in February 2007, but it is anticipated that dairy producers will continue to use composting facilities as a method for manure management.

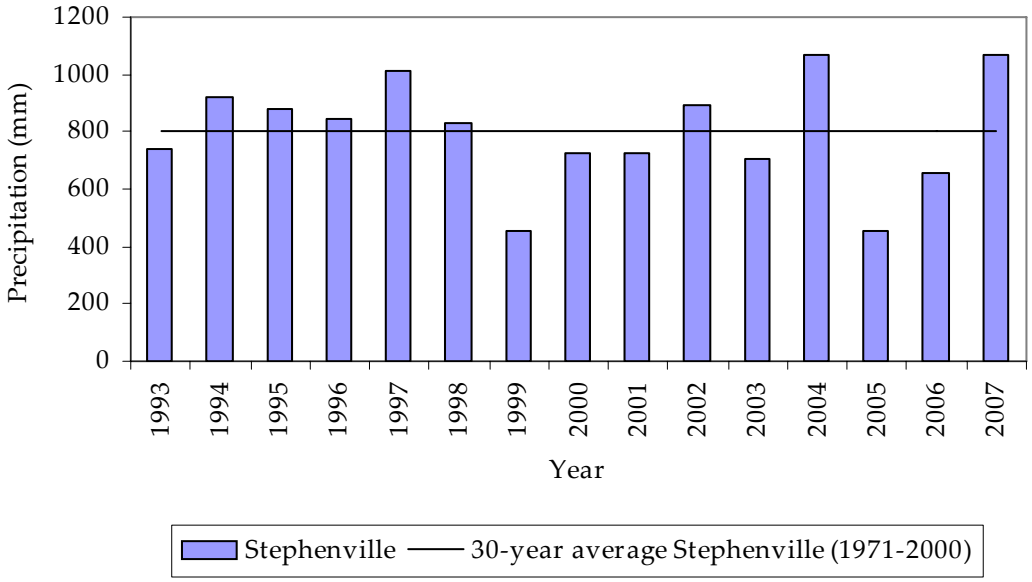
In addition to the manure composting program, an extensive effort has been made within the watershed to provide outreach to landowners, particularly dairy operators, to update WQMPs and develop CNMPs to include practices for nutrient management. Although the TMDL Implementation Plan for the North Bosque River was approved in 2002, the political and social climate for a variety of reasons, including litigation between the City of Waco and the Dairy Industry, has caused delays in the adoption of new practices by producers. As of 2006, only 12 CNMPs had been certified since initiation of the TMDLs. Encouragingly, in 2007, an additional 34 CNMPs were certified for CAFOs in the North Bosque River watershed.

A previous report shows that an assistance program conducted by the TSSWCB and local SWCD focused on 22 WQMPs in the Upper Leon and 9 WQMPs in the Cross Timbers SWCDs through 2005 for landowners within the North Bosque River watershed (McFarland and Millican, 2006). The most frequent conservation practices noted involved pasture planting, brush removal (chemical and mechanical), fencing, and water development via ponds and wells. While these WQMPs were not generally specific to dairy operations, these practices should help improve nutrient management in the watershed through better land use and improved flexibility in water management for crop and animal production.

While the slow adoption of WQMPs and CNMPs is one factor delaying improvements in water quality, it should be noted that changes in water quality associated with nonpoint source contributions often lag changes in land management, because of residual impacts from past management practices (Clausen et al., 1992; Meals, 1992, 1996; Nikolaidis et al., 1998). The length of this time lag can vary greatly, particularly with regard to phosphorus, based on whether the soil itself is acting as a sink or source of phosphorus (Sharpley, 1995; Sharpley and Rekolainen, 1997).

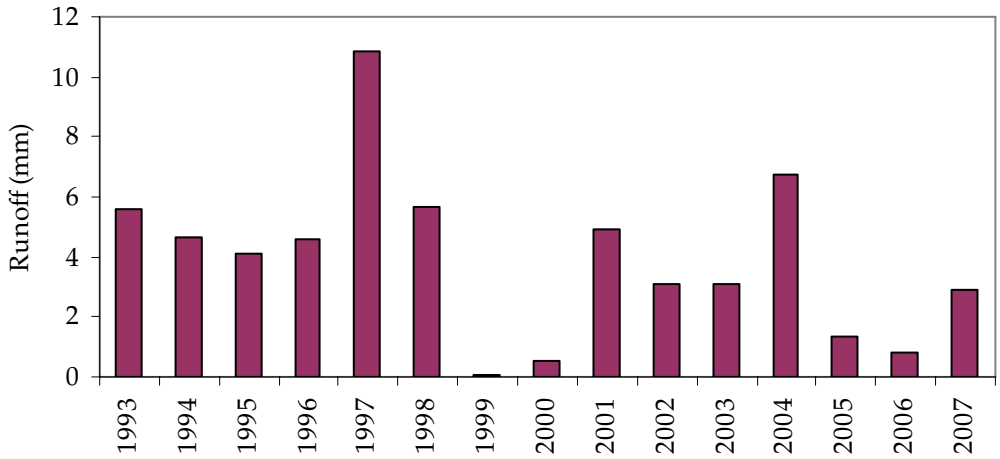
Also year to year variations in weather patterns can impact the ability to evaluate the effectiveness of implemented practices. Although flow-adjusting data prior to analysis helps account for hydrologic differences that occur between storm events, antecedent weather conditions and long-term weather patterns, especially in precipitation, may still have an affect on changes in water quality with changes in management practices that is not accounted for by streamflow adjustment. The "before" and "after" monitoring design is based on the assumption that weather conditions have, on average, remained the same during the two monitoring phases. However, historical precipitation data for Stephenville, Texas shows that precipitation after the start of the manure composting program in November 2000 was below average except in 2002, 2004, and 2007 (Figure 23).

**Figure 23** Temporal variability of annual precipitation at Stephenville, Texas. Data source: National Weather Service.



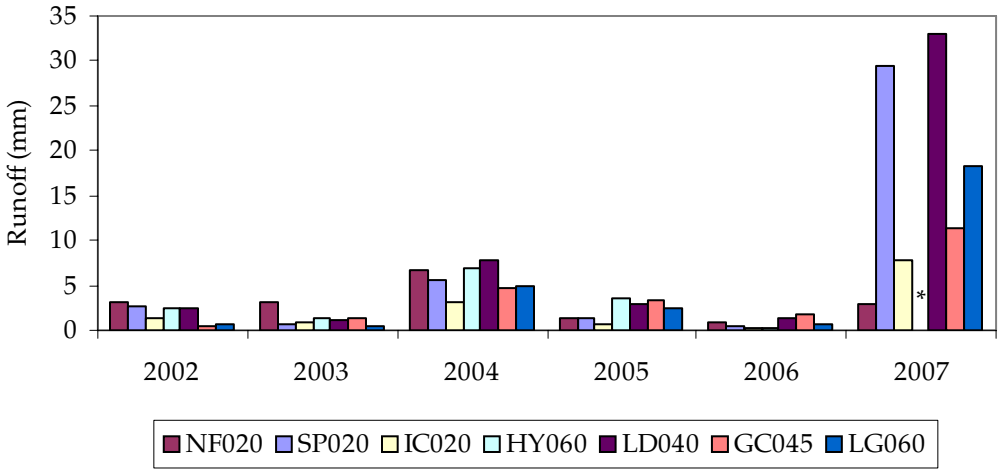

Similarly prior to adoption of the TMDLs in early 2001, many years showed precipitation well above the long-term average, although 1999 through 2001 were below average. These relatively dry conditions in 1999 through 2001 just prior and after adoption of the TMDLs may contribute to a lag in time between implementation of control practices and improvements in runoff water quality. For example at site NF020, barely any runoff occurred in 1999 and 2000 (Figure 24), which means that residual phosphorus associated with fertilizer or manure applied in 1999 and 2000 may have been associated with runoff in later years.

**Figure 24** Calculated annual runoff associated with site NF020.



Although shown for a shorter time period, runoff throughout the watershed was relatively low between 2002 and 2006 (Figure 25), and hydrologically less runoff occurred in 2006 than in 2005 even though more rain occurred in 2006 (see Figure 23). In 2007, annual rainfall was fairly comparable to 2004 (Figure 23), but runoff varied considerably throughout the watershed (Figure 25). The region between Stephenville and Hico had much more runoff than above Stephenville in 2007. Flooding conditions were noted at several of the sampling sites in 2007. Of note, site GM060 was washed downstream from its base, and site HY060 was completely under water due to runoff from heavy rains in June and July 2007.

**Figure 25** Calculated annual runoff at selected sites throughout the upper North Bosque River watershed. The asterisk in 2007 for HY060 indicates no data. Annual runoff could not be determined for site HY060 in 2007, because the sampling station was disabled for almost 20 days due to a event causing flooding conditions.




While rarely does a year represent "average" precipitation or runoff, it is expected that with continued monitoring, flows used to assess post-TMDL water quality will become more similar to pre-TMDL flow conditions decreasing the impact of year to year variability in weather conditions and making it easier to assess improvements associated with the implementation of management practices.

# CHAPTER 5

# Summary and Conclusions

Stream water quality was evaluated at 18 microwatershed sites located in the upper third of the North Bosque River watershed. This evaluation was done to assess changes with implementation of the North Bosque River TMDL for soluble reactive phosphorus and to target areas where the TSSWCB and local SWCDs might focus assistance with the development of WQMPs or CNMPs. The 18 stream sites evaluated represented a range of land uses within the watershed, although contributions from dairy waste application fields were a focus due to the large number of dairy operations located in the upper third of the watershed.

In comparing water quality between sites, sites with drainage areas comprised largely of intensive agriculture (WAFs and cropland) had higher nutrient concentrations than sites with drainage areas comprised largely of less intensive agriculture (wood/range and improved pasture) for both routine grab and storm event samples. A strong positive linear correlation was indicated between the percent area associated with intensive agriculture and the concentration of most water quality constituents. Land use alone does not explain all the variability in water quality concentrations. An evaluation of bacteria (*E. coli*) concentrations with flow indicated highly significant positive correlations at most sites with increasing concentrations with increasing flow. The large amount of scatter in bacteria data made it difficult to develop a general a flow-concentration relationship that could be applied between sites.

To evaluate trends in water quality over time, data were volume adjusted to help account for variability in flow conditions between months and years. Trend analyses were conducted for data collected between 2001 and 2007 at all 18 sites using the Kendall's tau statistic. No trends were generally indicated, although decreases in phosphorus concentrations were indicated at sites GB040 and GM060. A large amount of the land area above site GB040 is used as WAFs, although indications are that in recent years much of the manure generated in this drainage area has been hauled to composting facilities. Within the GM060 drainage area, there are not a large number of CAFOs or AFOs, but the TSSWCB has worked closely with landowners in this watershed on implementing WQMPs. While most sites did not indicate short-term changes in water quality over the seven years evaluated, this may be related to variability in weather patterns between monitoring years. Although data were volume adjusted prior to trend analysis, this only takes into account part of the variability in flow conditions from year to year. Many factors, such as antecedent conditions and the intensity of runoff during a given event, impact the flow-concentration relationship, but cannot be easily taken into account. For example, a relatively wet year might be expected to have higher water quality concentrations if preceded by a very dry year than a very wet year, because during a preceding dry year there would a greater opportunity for surface applied nutrients to build up and be washed off the following year than if the preceding year were wet.

Variations in land management practices will also impact changes in water quality. Extensive efforts have been made in the North Bosque River watershed as part of the TMDL Implementation Plan (TCEQ and TSSWCB, 2002) to reduce nutrient runoff through various outreach programs to landowners, particularly dairy operators. The number of certified CNMPs at CAFOs in the North Bosque River watershed has increased from one in 2004 to 34 in 2007. Nearly 50 CAFO permits are under technical review by TCEQ. These amended permits are based on revised rules that require dairy CAFOs in the Bosque River watershed to obtain individual permits, increase the design margin of safety for wastewater retention control structures to 25-yr/10-day rainfall event, implement CNMPs, and install vegetative filter/buffer strips with land application areas along with other requirements. Unfortunately, many of these management practices are only recently being put into effect. Many reasons, including a lawsuit between the City of Waco and the Dairy Industry have slowed the implementation of nutrient management practices, but implementation is now increasing and the impact of these practices should be more apparent with continued monitoring.

One facet of the TMDL Implementation Plan that has had a notable impact in managing manure nutrients is the Composted Manure Incentive Project and the Dairy Manure Export Support Project. These two projects have worked in concert in an effort to meet the TMDL set target of removing 50 percent of collectable manure from CAFOs and AFOs. These projects support the hauling of manure to composting facilities and the use of the composted manure outside the watershed, most notably by the Texas Department of Transportation for roadside revegetation. Over 700,000 tons of dairy manure have been hauled to composting facilities between November 2000 and February 2007. Long-term water quality data were evaluated at six sites (GB025, GB040, IC020, NF020, SC020, and SP020) with regard to implementation of the composting programs. These six sites represent a range of land uses and levels of participation in the composting program. Statistically significant reductions in $PO_4$-P concentrations were observed at sites GB025, GB040 and NF020. When normalized on both a per cow and land area basis, these three sites represented land areas with some of the highest levels of participation in the manure composting program.

Of note, significant changes in $PO_4$-P concentrations were also indicated at site SP020. Site SP020 is considered a least impacted site with no dairies and relatively little intensive agriculture in its drainage area. This decrease in $PO_4$-P concentrations at SP020, although highly significant, occurred at relatively low $PO_4$-P concentrations with mean event mean concentrations of 0.02 mg/L in both the "before" and "after" periods. It is suspected that improvements in the precision of laboratory techniques over the monitoring period for $PO_4$-P have played a role in the detection of changes in the relatively low $PO_4$-P concentrations, although other factors, such as differences in weather conditions and land use patterns could not be ruled out in explaining this significant decrease in storm $PO_4$-P concentrations. Regardless of the cause, the small absolute magnitude of the decrease at SP020 could not explain the much larger absolute decreases noted at sites GB025, GB040, and NF020.

Although the formal projects (CMIP and DMES) ended in 2006 and 2007, six of the seven manure composting facilities that have established businesses in the watershed are still active. Continued high participation of CAFOs and AFOs in manure

composting and eventual hauling out of the watershed would be anticipated to result in trends of improved water quality. Many of the CAFO permits in review by TCEQ indicate the use of haul-off to composting facilities as an option in how solid manure will be managed, so composting is an important avenue for improving water quality within the North Bosque River.

Responsibilities stemming from the North Bosque River TMDLs for phosphorus also require that the TSSWCB take nutrient management planning a step further by aiding in the development of CNMPs for permitted and WQMPs for unpermitted animal feeding operations in the watershed (TCEQ and TSSWCB, 2002). A CNMP targets not only animal waste application fields but the entire production system to ensure that both agricultural production goals and natural resource concerns dealing with nutrient and organic by-products and their adverse impacts on water quality are addressed. While nutrient management activities under a CNMP do not necessarily lead to the removal of manure from the watershed, as does the manure composting program, CNMPs should better direct utilization of manure on the land leading to decreased nutrient runoff.

With seven years of post implementation monitoring, the manure composting program has had a positive impact on stream water quality in the North Bosque River. The general decrease in $PO_4$-P concentrations at sites with the highest levels of manure removed per cow and drainage area (GB040, GB025, and NF020) is an indication that DMES project and CMIP were successful. The development and implementation of WQMPs and CNMPs are also important facets for improving water quality in the North Bosque River watershed, but evaluating their impact with regard to water quality improvements is more difficult in that only fairly recently have a significant number of plans been approved. There are some indications from reductions in stream nutrients noted in the Gilmer Creek watershed (GM060) that WQMPs are having an impact on water quality. It is anticipated that with continued monitoring, water quality improvements associated with CNMPs and WQMPs will become more apparent throughout the watershed.

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# APPENDIX A

# Summary Statistics for Grab Sample Data

All data analyses represent grab samples collected between January 1, 2001 and December 31, 2007. Exact dates will vary by site based on monitoring history.

**Table A–1** Summary Statistics for routine grab samples from site AL020 (N = number of samples).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| AL020 | $PO_4$-P (mg/L) | 0.193 | 0.132 | 0.195 | 0.001 | 0.887 | 83 |
| AL020 | Total-P (mg/L) | 0.34 | 0.27 | 0.27 | 0.01 | 1.16 | 82 |
| AL020 | $NH_3$-N (mg/L) | 0.086 | 0.056 | 0.087 | 0.008 | 0.401 | 83 |
| AL020 | $NO_2$-N + $NO_3$-N (mg/L) | 0.771 | 0.193 | 1.13 | 0.008 | 4.88 | 83 |
| AL020 | TKN (mg/L) | 1.15 | 1.02 | 0.72 | 0.10 | 4.44 | 83 |
| AL020 | TSS (mg/L) | 29 | 8 | 60 | 1 | 422 | 83 |
| AL020 | Water Temp. (°C) | 17.3 | 19.1 | 6.5 | 2.0 | 30.9 | 83 |
| AL020 | Conductivity (µmhos/cm) | 1000 | 934 | 576 | 97 | 2610 | 83 |
| AL020 | DO (mg/L) | 6.8 | 6.6 | 3.0 | 1.16 | 13.4 | 83 |
| AL020 | pH (standard units) | 7.9 | 7.9 | 0.27 | 7.4 | 9 | 83 |
| AL020 | Fecal Coliform (colonies/100ml) | 3100 | 350 | 12700 | 12 | 69000 | 29 |
| AL020 | *Escherichia coli* (colonies/100ml) | 2270 | 225 | 9080 | 3.1 | 54000 | 71 |

**Table A–2** Summary Statistics for routine grab samples from site DB035 (N = number of samples).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| DB035 | $PO_4$-P (mg/L) | 0.504 | 0.484 | 0.331 | 0.058 | 1.50 | 49 |
| DB035 | Total-P (mg/L) | 0.70 | 0.66 | 0.40 | 0.02 | 1.7 | 49 |
| DB035 | $NH_3$-N (mg/L) | 0.123 | 0.062 | 0.164 | 0.007 | 0.685 | 49 |
| DB035 | $NO_2$-N + $NO_3$-N (mg/L) | 1.370 | 0.887 | 1.58 | 0.004 | 6.03 | 49 |
| DB035 | TKN (mg/L) | 1.70 | 1.55 | 0.77 | 0.25 | 4.22 | 49 |
| DB035 | TSS (mg/L) | 21 | 12 | 28 | 2 | 144 | 49 |
| DB035 | Water Temp. (°C) | 16.4 | 16.6 | 5.9 | 6.2 | 26.5 | 49 |
| DB035 | Conductivity (µmhos/cm) | 1040 | 987 | 560 | 305 | 2350 | 49 |
| DB035 | DO (mg/L) | 9.5 | 9.3 | 3.4 | 3.8 | 16.5 | 49 |
| DB035 | pH (standard units) | 8.1 | 8.0 | 0.2 | 7.7 | 8.5 | 49 |
| DB035 | Fecal Coliform (colonies/100ml) | 1340 | 270 | 3150 | 52 | 13900 | 22 |
| DB035 | *Escherichia coli* (colonies/100ml) | 6490 | 355 | 25490 | 32 | 141000 | 46 |

**Table A–3** Summary Statistics for routine grab samples from site DC040 (N = number of samples).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| DC040 | $PO_4$-P (mg/L) | 0.034 | 0.015 | 0.057 | 0.001 | 0.364 | 158 |
| DC040 | Total-P (mg/L) | 0.10 | 0.08 | 0.09 | 0.01 | 0.59 | 158 |
| DC040 | $NH_3$-N (mg/L) | 0.034 | 0.016 | 0.039 | 0.007 | 0.243 | 158 |
| DC040 | $NO_2$-N + $NO_3$-N (mg/L) | 0.160 | 0.027 | 0.313 | 0.004 | 1.97 | 158 |
| DC040 | TKN (mg/L) | 0.46 | 0.38 | 0.35 | 0.04 | 2.28 | 158 |
| DC040 | TSS (mg/L) | 72 | 4 | 10 | 1 | 68 | 158 |
| DC040 | Water Temp. (°C) | 17.2 | 18.0 | 6.7 | 2.1 | 29.7 | 158 |
| DC040 | Conductivity (µmhos/cm) | 588 | 588 | 114 | 305 | 1070 | 158 |
| DC040 | DO (mg/L) | 7.6 | 7.3 | 2.7 | 1.3 | 14.4 | 158 |
| DC040 | pH (standard units) | 7.9 | 7.9 | 0.19 | 7.3 | 8.5 | 158 |
| DC040 | Fecal Coliform (colonies/100ml) | 711 | 134 | 2950 | 12 | 20000 | 46 |
| DC040 | *Escherichia coli* (colonies/100ml) | 798 | 116 | 3660 | 5 | 38700 | 128 |

**Table A–4** Summary statistics for routine grab samples from site GB020 (N = number of samples).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| GB020 | $PO_4$-P (mg/L) | 5.03 | 5.21 | 2.64 | 0.691 | 7.60 | 6 |
| GB020 | Total-P (mg/L) | 11.1 | 7.27 | 9.31 | 3.36 | 28.2 | 7 |
| GB020 | $NH_3$-N (mg/L) | 0.485 | 0.232 | 0.623 | 0.079 | 1.59 | 5 |
| GB020 | $NO_2$-N + $NO_3$-N (mg/L) | 3.64 | 0.932 | 4.04 | 0.240 | 9.87 | 7 |
| GB020 | TKN (mg/L) | 41.2 | 6.09 | 68.2 | 3.04 | 187 | 7 |
| GB020 | TSS (mg/L) | 370 | 122 | 716 | 2 | 1980 | 7 |
| GB020 | Water Temp. (°C) | 11.6 | 7.0 | 8.2 | 4.1 | 23.6 | 7 |
| GB020 | Conductivity (µmhos/cm) | 1120 | 519 | 1170 | 178 | 3270 | 7 |
| GB020 | DO (mg/L) | 8.6 | 8.8 | 2.9 | 5.2 | 11.6 | 7 |
| GB020 | pH (standard units) | 8.2 | 8.1 | 0.2 | 7.9 | 8.5 | 7 |
| GB020 | Fecal Coliform (colonies/100ml) | 261000 | 261000 | . | 9700 | 512000 | 2 |
| GB020 | *Escherichia coli* (colonies/100ml) | 165000 | 20100 | 235000 | 7270 | 498000 | 6 |

**Table A–5** Summary statistics for routine grab samples from site GB025 (N = number of samples).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| GB025 | $PO_4$-P (mg/L) | 5.01 | 5.01 | . | 3.24 | 6.77 | 2 |
| GB025 | Total-P (mg/L) | 6.11 | 6.11 | . | 4.37 | 7.84 | 2 |
| GB025 | $NH_3$-N (mg/L) | 0.879 | 0.879 | . | 0.457 | 1.30 | 2 |
| GB025 | $NO_2$-N + $NO_3$-N (mg/L) | 8.40 | 8.40 | . | 5.40 | 11.4 | 2 |
| GB025 | TKN (mg/L) | 5.43 | 5.43 | . | 4.64 | 6.21 | 2 |
| GB025 | TSS (mg/L) | 57 | 57 | . | 47 | 67 | 2 |
| GB025 | Water Temp. (°C) | 8.6 | 8.6 | . | 6.9 | 10.4 | 2 |
| GB025 | Conductivity (µmhos/cm) | 489 | 489 | . | 393 | 585 | 2 |
| GB025 | DO (mg/L) | 10.3 | 10.3 | . | 9.3 | 11.3 | 2 |
| GB025 | pH (standard units) | 8.0 | 8.0 | . | 7.8 | 8.2 | 2 |
| GB025 | Fecal Coliform (colonies/100ml) | 22000 | 22000 | . | 22000 | 22000 | 1 |
| GB025 | *Escherichia coli* (colonies/100ml) | 30400 | 30400 | . | 22000 | 38700 | 2 |

**Table A–6** Summary statistics for routine grab samples from site GB040 (N = number of samples).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| GB040 | $PO_4$-P (mg/L) | 0.825 | 0.607 | 0.853 | 0.007 | 4.36 | 49 |
| GB040 | Total-P (mg/L) | 2.17 | 0.860 | 7.28 | 0.020 | 51.3 | 49 |
| GB040 | $NH_3$-N (mg/L) | 0.505 | 0.389 | 0.616 | 0.018 | 3.79 | 46 |
| GB040 | $NO_2$-N + $NO_3$-N (mg/L) | 15.5 | 15.5 | 12.1 | 0.166 | 40.8 | 48 |
| GB040 | TKN (mg/L) | 7.71 | 2.59 | 29.5 | 0.53 | 204 | 49 |
| GB040 | TSS (mg/L) | 46 | 22 | 90 | 2 | 630 | 49 |
| GB040 | Water Temp. (°C) | 15.8 | 16.5 | 6.8 | 3.7 | 27.4 | 49 |
| GB040 | Conductivity (µmhos/cm) | 3050 | 3280 | 1260 | 405 | 6770 | 49 |
| GB040 | DO (mg/L) | 10.3 | 9.8 | 4.3 | 3.4 | 23.2 | 49 |
| GB040 | pH (standard units) | 8.2 | 8.2 | 0.2 | 7.6 | 8.7 | 49 |
| GB040 | Fecal Coliform (colonies/100ml) | 9670 | 8350 | 9030 | 700 | 38000 | 24 |
| GB040 | *Escherichia coli* (colonies/100ml) | 15400 | 6200 | 23700 | 400 | 112000 | 37 |

**Table A–7** Summary statistics for routine grab samples from site GC045 (N = number of samples).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| GC045 | $PO_4$-P (mg/L) | 0.078 | 0.017 | 0.141 | 0.001 | 0.889 | 79 |
| GC045 | Total-P (mg/L) | 0.18 | 0.11 | 0.19 | 0.01 | 1.11 | 79 |
| GC045 | $NH_3$-N (mg/L) | 0.069 | 0.045 | 0.086 | 0.008 | 0.586 | 79 |
| GC045 | $NO_2$-N + $NO_3$-N (mg/L) | 5.09 | 2.82 | 5.70 | 0.004 | 22.2 | 79 |
| GC045 | TKN (mg/L) | 1.01 | 0.85 | 0.59 | 0.10 | 2.31 | 79 |
| GC045 | TSS (mg/L) | 21 | 13 | 23 | 2 | 112 | 78 |
| GC045 | Water Temp. (°C) | 19.2 | 21.0 | 6.1 | 5.5 | 28.0 | 79 |
| GC045 | Conductivity (µmhos/cm) | 718 | 697 | 246 | 306 | 1250 | 79 |
| GC045 | DO (mg/L) | 7.7 | 7.4 | 2.1 | 3.5 | 13.5 | 79 |
| GC045 | pH (standard units) | 7.9 | 7.9 | 0.2 | 7.3 | 8.4 | 79 |
| GC045 | Fecal Coliform (colonies/100ml) | 497 | 163 | 1010 | 2 | 4500 | 21 |
| GC045 | *Escherichia coli* (colonies/100ml) | 3980 | 173 | 29100 | 0 | 242000 | 69 |

**Table A–8** Summary statistics for routine grab samples from site GM060 (N = number of samples).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| GM060 | $PO_4$-P (mg/L) | 0.088 | 0.025 | 0.156 | 0.002 | 1.03 | 102 |
| GM060 | Total-P (mg/L) | 0.17 | 0.09 | 0.21 | 0.01 | 1.46 | 102 |
| GM060 | $NH_3$-N (mg/L) | 0.048 | 0.021 | 0.105 | 0.007 | 0.917 | 102 |
| GM060 | $NO_2$-N + $NO_3$-N (mg/L) | 0.112 | 0.020 | 0.280 | 0.004 | 2.16 | 102 |
| GM060 | TKN (mg/L) | 0.55 | 0.44 | 0.46 | 0.06 | 2.78 | 102 |
| GM060 | TSS (mg/L) | 12 | 3 | 54 | 1 | 544 | 102 |
| GM060 | Water Temp. (°C) | 18.2 | 18.2 | 7.7 | 2.5 | 37.4 | 102 |
| GM060 | Conductivity (µmhos/cm) | 879 | 801 | 320 | 160 | 1720 | 102 |
| GM060 | DO (mg/L) | 9.8 | 9.7 | 2.1 | 5.2 | 15.1 | 102 |
| GM060 | pH (standard units) | 8.1 | 8.1 | 0.2 | 7.5 | 8.8 | 102 |
| GM060 | Fecal Coliform (colonies/100ml) | 794 | 35 | 4220 | 2 | 26100 | 38 |
| GM060 | *Escherichia coli* (colonies/100ml) | 915 | 29 | 3755 | 0 | 25000 | 85 |

**Table A–9** Summary statistics for routine grab samples from site HY060 (N = number of samples).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| HY060 | $PO_4$-P (mg/L) | 0.007 | 0.002 | 0.014 | 0.001 | 0.102 | 92 |
| HY060 | Total-P (mg/L) | 0.07 | 0.06 | 0.06 | 0.01 | 0.48 | 92 |
| HY060 | $NH_3$-N (mg/L) | 0.026 | 0.012 | 0.025 | 0.007 | 0.163 | 92 |
| HY060 | $NO_2$-N + $NO_3$-N (mg/L) | 0.525 | 0.038 | 0.979 | 0.004 | 4.06 | 92 |
| HY060 | TKN (mg/L) | 0.34 | 0.30 | 0.25 | 0.06 | 1.30 | 92 |
| HY060 | TSS (mg/L) | 4 | 2 | 9 | 1 | 90 | 92 |
| HY060 | Water Temp. (°C) | 19.0 | 20.9 | 6.5 | 5.6 | 28.0 | 92 |
| HY060 | Conductivity (µmhos/cm) | 517 | 534 | 78 | 287 | 643 | 92 |
| HY060 | DO (mg/L) | 8.3 | 7.9 | 2.1 | 4.4 | 14.8 | 92 |
| HY060 | pH (standard units) | 7.8 | 7.8 | 0.2 | 7.3 | 8.2 | 92 |
| HY060 | Fecal Coliform (colonies/100ml) | 139 | 66 | 257 | 5 | 1420 | 37 |
| HY060 | *Escherichia coli* (colonies/100ml) | 112 | 56 | 184 | 2 | 1200 | 81 |

**Table A–10** Summary Statistics for routine grab samples from site IC020 (N = number of samples).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| IC020 | $PO_4$-P (mg/L) | 0.351 | 0.196 | 0.495 | 0.007 | 3.01 | 56 |
| IC020 | Total-P (mg/L) | 0.60 | 0.40 | 0.76 | 0.01 | 4.16 | 56 |
| IC020 | $NH_3$-N (mg/L) | 0.257 | 0.052 | 0.610 | 0.008 | 3.68 | 55 |
| IC020 | $NO_2$-N + $NO_3$-N (mg/L) | 1.914 | 1.595 | 1.927 | 0.006 | 8.72 | 56 |
| IC020 | TKN (mg/L) | 2.22 | 1.61 | 2.30 | 0.10 | 15.3 | 56 |
| IC020 | TSS (mg/L) | 22 | 10 | 41 | 2 | 240 | 56 |
| IC020 | Water Temp. (°C) | 19.1 | 20.5 | 6.8 | 6.2 | 31.3 | 56 |
| IC020 | Conductivity (µmhos/cm) | 1238 | 1185 | 535 | 172 | 2800 | 56 |
| IC020 | DO (mg/L) | 12.3 | 12.4 | 3.0 | 6.1 | 20.8 | 56 |
| IC020 | pH (standard units) | 8.3 | 8.3 | 0.3 | 7.5 | 8.9 | 56 |
| IC020 | Fecal Coliform (colonies/100ml) | 13400 | 782 | 51300 | 0 | 219000 | 18 |
| IC020 | *Escherichia coli* (colonies/100ml) | 4480 | 400 | 18900 | 0 | 123000 | 42 |

**Table A–11** Summary statistics for routine grab samples from site LD040 (N = number of samples).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| LD040 | $PO_4$-P (mg/L) | 0.564 | 0.447 | 0.446 | 0.092 | 2.47 | 44 |
| LD040 | Total-P (mg/L) | 0.89 | 0.59 | 1.06 | 0.14 | 5.40 | 44 |
| LD040 | $NH_3$-N (mg/L) | 0.230 | 0.073 | 0.523 | 0.010 | 2.52 | 42 |
| LD040 | $NO_2$-N + $NO_3$-N (mg/L) | 3.27 | 2.06 | 3.71 | 0.015 | 14.4 | 44 |
| LD040 | TKN (mg/L) | 3.35 | 1.48 | 7.21 | 0.10 | 36.6 | 44 |
| LD040 | TSS (mg/L) | 22 | 10 | 28 | 1 | 127 | 44 |
| LD040 | Water Temp. (°C) | 17.4 | 18.0 | 6.2 | 6.4 | 26.8 | 44 |
| LD040 | Conductivity (µmhos/cm) | 1229 | 1210 | 512 | 127 | 2390 | 44 |
| LD040 | DO (mg/L) | 8.3 | 8.2 | 2.4 | 2.7 | 13.2 | 44 |
| LD040 | pH (standard units) | 7.9 | 7.9 | 0.2 | 7.5 | 8.3 | 44 |
| LD040 | Fecal Coliform (colonies/100ml) | 6170 | 1400 | 9710 | 46 | 24200 | 9 |
| LD040 | *Escherichia coli* (colonies/100ml) | 9530 | 785 | 20100 | 11 | 77000 | 40 |

**Table A–12** Summary statistics for routine grab samples from site LG060 (N = number of samples).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| LG060 | $PO_4$-P (mg/L) | 0.093 | 0.044 | 0.175 | 0.002 | 1.39 | 74 |
| LG060 | Total-P (mg/L) | 0.21 | 0.15 | 0.23 | 0.01 | 1.73 | 74 |
| LG060 | $NH_3$-N (mg/L) | 0.083 | 0.054 | 0.118 | 0.008 | 0.895 | 74 |
| LG060 | $NO_2$-N + $NO_3$-N (mg/L) | 0.494 | 0.222 | 0.643 | 0.007 | 2.48 | 74 |
| LG060 | TKN (mg/L) | 1.19 | 0.97 | 1.13 | 0.10 | 8.85 | 74 |
| LG060 | TSS (mg/L) | 22 | 11 | 29 | 2 | 171 | 74 |
| LG060 | Water Temp. (°C) | 18.4 | 20.0 | 6.4 | 4.3 | 29.0 | 73 |
| LG060 | Conductivity (µmhos/cm) | 639 | 634 | 227 | 171 | 1050 | 73 |
| LG060 | DO (mg/L) | 9.1 | 8.5 | 2.5 | 4.7 | 15.2 | 73 |
| LG060 | pH (standard units) | 8.0 | 8.1 | 0.2 | 7.7 | 8.6 | 73 |
| LG060 | Fecal Coliform (colonies/100ml) | 4430 | 755 | 1040 | 70 | 39500 | 21 |
| LG060 | *Escherichia coli* (colonies/100ml) | 6650 | 345 | 27500 | 50 | 199000 | 63 |

**Table A–13** Summary statistics for routine grab samples from site NF009 (N = number of samples).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| NF009 | $PO_4$-P (mg/L) | 0.196 | 0.121 | 0.185 | 0.008 | 0.750 | 68 |
| NF009 | Total-P (mg/L) | 0.39 | 0.32 | 0.30 | 0.01 | 1.63 | 68 |
| NF009 | $NH_3$-N (mg/L) | 0.176 | 0.053 | 0.280 | 0.007 | 1.42 | 67 |
| NF009 | $NO_2$-N + $NO_3$-N (mg/L) | 0.439 | 0.047 | 0.836 | 0.004 | 4.01 | 68 |
| NF009 | TKN (mg/L) | 1.77 | 1.30 | 2.00 | 0.10 | 15.9 | 68 |
| NF009 | TSS (mg/L) | 29 | 16 | 39 | 1 | 274 | 68 |
| NF009 | Water Temp. (°C) | 15.8 | 16.8 | 6.3 | 2.6 | 26.8 | 68 |
| NF009 | Conductivity (µmhos/cm) | 2053 | 1950 | 986 | 270 | 4290 | 68 |
| NF009 | DO (mg/L) | 7.3 | 7.1 | 3.3 | 2.0 | 16.9 | 68 |
| NF009 | pH (standard units) | 7.9 | 7.8 | 0.2 | 7.4 | 8.7 | 68 |
| NF009 | Fecal Coliform (colonies/100ml) | 1290 | 210 | 2930 | 22 | 12400 | 21 |
| NF009 | *Escherichia coli* (colonies/100ml) | 2980 | 534 | 11900 | 22 | 92100 | 60 |

**Table A–14** Summary statistics for routine grab samples from site NF020 (N = number of samples).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| NF020 | $PO_4$-P (mg/L) | 1.19 | 1.09 | 0.845 | 0.156 | 4.08 | 25 |
| NF020 | Total-P (mg/L) | 1.62 | 1.37 | 1.09 | 0.22 | 4.57 | 25 |
| NF020 | $NH_3$-N (mg/L) | 0.301 | 0.105 | 0.404 | 0.008 | 1.69 | 26 |
| NF020 | $NO_2$-N + $NO_3$-N (mg/L) | 0.882 | 0.368 | 1.28 | 0.004 | 5.28 | 26 |
| NF020 | TKN (mg/L) | 3.43 | 2.59 | 2.19 | 1.28 | 9.74 | 26 |
| NF020 | TSS (mg/L) | 35 | 20 | 43 | 2 | 192 | 26 |
| NF020 | Water Temp. (°C) | 14.1 | 14.0 | 5.4 | 5.6 | 25.2 | 26 |
| NF020 | Conductivity (µmhos/cm) | 2655 | 2120 | 1576 | 377 | 5400 | 26 |
| NF020 | DO (mg/L) | 8.6 | 8.8 | 2.8 | 4.2 | 15.5 | 26 |
| NF020 | pH (standard units) | 8.0 | 8.1 | 0.2 | 7.6 | 8.5 | 26 |
| NF020 | Fecal Coliform (colonies/100ml) | 76900 | 12500 | 98400 | 166 | 189000 | 5 |
| NF020 | *Escherichia coli* (colonies/100ml) | 16100 | 1360 | 39600 | 73 | 144000 | 22 |

**Table A–15** Summary statistics for routine grab samples from site NF050 (N = number of samples).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| NF050 | $PO_4$-P (mg/L) | 0.345 | 0.308 | 0.196 | 0.045 | 0.796 | 47 |
| NF050 | Total-P (mg/L) | 0.53 | 0.55 | 0.26 | 0.07 | 1.09 | 47 |
| NF050 | $NH_3$-N (mg/L) | 0.114 | 0.050 | 0.191 | 0.010 | 1.05 | 47 |
| NF050 | $NO_2$-N + $NO_3$-N (mg/L) | 0.286 | 0.235 | 0.304 | 0.004 | 1.55 | 47 |
| NF050 | TKN (mg/L) | 1.87 | 1.78 | 0.65 | 0.48 | 4.07 | 47 |
| NF050 | TSS (mg/L) | 23 | 19 | 22 | 2 | 133 | 47 |
| NF050 | Water Temp. (°C) | 17.3 | 17.5 | 6.6 | 5.9 | 25.9 | 47 |
| NF050 | Conductivity (µmhos/cm) | 647 | 465 | 443 | 194 | 1740 | 47 |
| NF050 | DO (mg/L) | 8.3 | 7.7 | 2.7 | 2.4 | 14.9 | 47 |
| NF050 | pH (standard units) | 8.2 | 8.2 | 0.2 | 7.8 | 9.1 | 47 |
| NF050 | Fecal Coliform (colonies/100ml) | 4360 | 1110 | 6340 | 0 | 17000 | 14 |
| NF050 | *Escherichia coli* (colonies/100ml) | 5020 | 741 | 13800 | 0 | 77000 | 46 |

**Table A–16** Summary statistics for routine grab samples from site SC020 (N = number of samples).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| SC020 | $PO_4$-P (mg/L) | 0.060 | 0.028 | 0.102 | 0.001 | 0.630 | 109 |
| SC020 | Total-P (mg/L) | 0.14 | 0.11 | 0.15 | 0.01 | 0.84 | 109 |
| SC020 | $NH_3$-N (mg/L) | 0.059 | 0.038 | 0.075 | 0.007 | 0.529 | 109 |
| SC020 | $NO_2$-N + $NO_3$-N (mg/L) | 0.434 | 0.280 | 0.469 | 0.004 | 2.61 | 109 |
| SC020 | TKN (mg/L) | 0.67 | 0.56 | 0.48 | 0.06 | 2.34 | 109 |
| SC020 | TSS (mg/L) | 14 | 4 | 25 | 1 | 171 | 108 |
| SC020 | Water Temp. (°C) | 16.0 | 16.6 | 6.8 | 2.9 | 27.2 | 109 |
| SC020 | Conductivity (µmhos/cm) | 670 | 670 | 159 | 142 | 1100 | 109 |
| SC020 | DO (mg/L) | 8.9 | 9.0 | 3.2 | 1.4 | 14.6 | 109 |
| SC020 | pH (standard units) | 8.0 | 8.0 | 0.2 | 7.2 | 8.4 | 109 |
| SC020 | Fecal Coliform (colonies/100ml) | 2170 | 450 | 5680 | 10 | 30000 | 33 |
| SC020 | *Escherichia coli* (colonies/100ml) | 1860 | 276 | 6980 | 3 | 57900 | 89 |

**Table A–17** Summary statistics for routine grab samples from site SF085 (N = number of samples).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| SF085 | $PO_4$-P (mg/L) | 0.232 | 0.195 | 0.185 | 0.003 | 1.22 | 127 |
| SF085 | Total-P (mg/L) | 0.34 | 0.29 | 0.26 | 0.01 | 1.63 | 127 |
| SF085 | $NH_3$-N (mg/L) | 0.050 | 0.028 | 0.068 | 0.007 | 0.541 | 127 |
| SF085 | $NO_2$-N + $NO_3$-N (mg/L) | 0.304 | 0.170 | 0.377 | 0.007 | 2.23 | 127 |
| SF085 | TKN (mg/L) | 0.90 | 0.75 | 0.71 | 0.10 | 3.87 | 127 |
| SF085 | TSS (mg/L) | 12 | 4 | 19 | 1 | 146 | 127 |
| SF085 | Water Temp. (°C) | 16.8 | 17.3 | 6.8 | 2.1 | 28.7 | 126 |
| SF085 | Conductivity (µmhos/cm) | 731 | 728 | 308 | 185 | 1630 | 126 |
| SF085 | DO (mg/L) | 8.7 | 8.3 | 3.2 | 2.7 | 16.6 | 126 |
| SF085 | pH (standard units) | 8.1 | 8.1 | 0.2 | 7.6 | 9.0 | 126 |
| SF085 | Fecal Coliform (colonies/100ml) | 585 | 157 | 1380 | 5 | 7400 | 44 |
| SF085 | *Escherichia coli* (colonies/100ml) | 3860 | 190 | 24500 | 3 | 242000 | 102 |

**Table A–18** Summary statistics for routine grab samples from site SP020 (N = number of samples).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| SP020 | $PO_4$-P (mg/L) | 0.005 | 0.002 | 0.008 | 0.001 | 0.048 | 106 |
| SP020 | Total-P (mg/L) | 0.06 | 0.05 | 0.04 | 0.01 | 0.28 | 106 |
| SP020 | $NH_3$-N (mg/L) | 0.020 | 0.012 | 0.017 | 0.007 | 0.096 | 106 |
| SP020 | $NO_2$-N + $NO_3$-N (mg/L) | 0.075 | 0.020 | 0.191 | 0.004 | 1.18 | 106 |
| SP020 | TKN (mg/L) | 0.25 | 0.20 | 0.20 | 0.02 | 1.00 | 106 |
| SP020 | TSS (mg/L) | 5 | 2 | 7 | 1 | 43 | 106 |
| SP020 | Water Temp. (°C) | 17.1 | 17.4 | 5.9 | 6.6 | 30.1 | 106 |
| SP020 | Conductivity (µmhos/cm) | 501 | 512 | 57 | 317 | 597 | 106 |
| SP020 | DO (mg/L) | 9.0 | 8.7 | 1.4 | 6.0 | 12.3 | 106 |
| SP020 | pH (standard units) | 7.9 | 7.9 | 0.2 | 7.5 | 8.7 | 106 |
| SP020 | Fecal Coliform (colonies/100ml) | 284 | 110 | 845 | 19 | 5200 | 37 |
| SP020 | *Escherichia coli* (colonies/100ml) | 284 | 61 | 833 | 5 | 5040 | 85 |

# APPENDIX B

# Summary Statistics for Storm Events

All data analyses represent storms evaluated between January 1, 2001 and December 31, 2007. Exact dates of data collected will vary by site based on monitoring history.

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

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| AL020 | $PO_4$-P (mg/L) | 0.285 | 0.238 | 0.216 | 0.001 | 0.915 | 78 |
| AL020 | Total-P (mg/L) | 0.64 | 0.62 | 0.45 | 0.06 | 1.62 | 78 |
| AL020 | $NH_3$-N (mg/L) | 0.091 | 0.061 | 0.090 | 0.007 | 0.461 | 78 |
| AL020 | $NO_2$-N + $NO_3$-N (mg/L) | 0.983 | 0.829 | 0.995 | 0.011 | 5.34 | 78 |
| AL020 | TKN (mg/L) | 2.04 | 1.82 | 1.25 | 0.10 | 5.98 | 78 |
| AL020 | TSS (mg/L) | 198 | 53 | 285 | 2 | 1390 | 78 |
| AL020 | *Escherichia coli* (colonies/100ml) | 21100 | 1410 | 48100 | 17 | 242000 | 116 |

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

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| DB035 | $PO_4$-P (mg/L) | 0.583 | 0.523 | 0.484 | 0.061 | 4.21 | 84 |
| DB035 | Total-P (mg/L) | 0.97 | 0.91 | 0.67 | 0.20 | 5.74 | 84 |
| DB035 | $NH_3$-N (mg/L) | 0.209 | 0.094 | 0.320 | 0.007 | 2.16 | 84 |
| DB035 | $NO_2$-N + $NO_3$-N (mg/L) | 0.964 | 0.702 | 1.02 | 0.020 | 7.45 | 84 |
| DB035 | TKN (mg/L) | 2.26 | 2.00 | 1.12 | 0.80 | 7.89 | 84 |
| DB035 | TSS (mg/L) | 140 | 68 | 194 | 5 | 1180 | 84 |
| DB035 | *Escherichia coli* (colonies/100ml) | 21400 | 4310 | 51000 | 78 | 242000 | 26 |

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

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| DC040 | $PO_4$-P (mg/L) | 0.086 | 0.048 | 0.091 | 0.001 | 0.396 | 98 |
| DC040 | Total-P (mg/L) | 0.30 | 0.18 | 0.33 | 0.01 | 2.19 | 97 |
| DC040 | $NH_3$-N (mg/L) | 0.082 | 0.044 | 0.138 | 0.007 | 0.893 | 98 |
| DC040 | $NO_2$-N + $NO_3$-N (mg/L) | 0.355 | 0.256 | 0.364 | 0.007 | 1.69 | 98 |
| DC040 | TKN (mg/L) | 1.29 | 0.93 | 1.24 | 0.10 | 6.90 | 98 |
| DC040 | TSS (mg/L) | 180 | 26 | 338 | 1 | 1930 | 98 |
| DC040 | *Escherichia coli* (colonies/100ml) | 4160 | 921 | 6450 | 140 | 29100 | 35 |

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

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| GB020 | $PO_4$-P (mg/L) | 3.27 | 2.92 | 1.74 | 0.544 | 7.20 | 47 |
| GB020 | Total-P (mg/L) | 4.46 | 4.51 | 1.93 | 1.19 | 9.24 | 47 |
| GB020 | $NH_3$-N (mg/L) | 0.683 | 0.391 | 0.808 | 0.050 | 3.68 | 46 |
| GB020 | $NO_2$-N + $NO_3$-N (mg/L) | 3.10 | 2.51 | 3.15 | 0.02 | 19.3 | 47 |
| GB020 | TKN (mg/L) | 6.26 | 4.78 | 3.62 | 2.22 | 17.3 | 47 |
| GB020 | TSS (mg/L) | 542 | 139 | 1090 | 3 | 5600 | 47 |
| GB020 | *Escherichia coli* (colonies/100ml) | 51400 | 25900 | 67500 | 2160 | 242000 | 21 |

**Table B–5** Storm event summary statistics for site GB025 (N = number of events).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| GB025 | $PO_4$-P (mg/L) | 1.44 | 1.27 | 1.08 | 0.22 | 4.74 | 57 |
| GB025 | Total-P (mg/L) | 3.20 | 2.99 | 1.36 | 0.843 | 6.21 | 57 |
| GB025 | $NH_3$-N (mg/L) | 0.587 | 0.284 | 0.861 | 0.063 | 4.51 | 57 |
| GB025 | $NO_2$-N + $NO_3$-N (mg/L) | 1.64 | 1.12 | 1.55 | 0.092 | 7.50 | 57 |
| GB025 | TKN (mg/L) | 8.76 | 6.68 | 5.76 | 1.93 | 28.4 | 57 |
| GB025 | TSS (mg/L) | 2000 | 733 | 3040 | 56 | 14500 | 57 |
| GB025 | *Escherichia coli* (colonies/100ml) | 242000 | 242000 | . | 242000 | 242000 | 1 |

**Table B–6** Storm event summary statistics for site GB040 (N = number of events).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| GB040 | $PO_4$-P (mg/L) | 1.02 | 1.02 | 0.421 | 0.184 | 1.97 | 65 |
| GB040 | Total-P (mg/L) | 2.69 | 2.29 | 1.56 | 0.33 | 9.39 | 65 |
| GB040 | $NH_3$-N (mg/L) | 0.561 | 0.419 | 0.471 | 0.039 | 2.44 | 65 |
| GB040 | $NO_2$-N + $NO_3$-N (mg/L) | 4.87 | 2.38 | 6.51 | 0.157 | 34.1 | 65 |
| GB040 | TKN (mg/L) | 7.99 | 6.43 | 6.08 | 1.32 | 36.5 | 65 |
| GB040 | TSS (mg/L) | 1830 | 598 | 3815 | 65 | 23400 | 65 |
| GB040 | *Escherichia coli* (colonies/100ml) | 80500 | 51400 | 85800 | 299 | 242000 | 44 |

**Table B–7** Storm event summary statistics for site GC045 (N = number of events).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| GC045 | $PO_4$-P (mg/L) | 0.127 | 0.105 | 0.116 | 0.001 | 0.421 | 65 |
| GC045 | Total-P (mg/L) | 0.36 | 0.34 | 0.26 | 0.02 | 1.14 | 65 |
| GC045 | $NH_3$-N (mg/L) | 0.088 | 0.059 | 0.094 | 0.007 | 0.421 | 65 |
| GC045 | $NO_2$-N + $NO_3$-N (mg/L) | 3.82 | 1.44 | 5.15 | 0.076 | 21.97 | 65 |
| GC045 | TKN (mg/L) | 1.71 | 1.56 | 0.97 | 0.29 | 4.93 | 65 |
| GC045 | TSS (mg/L) | 158 | 58 | 254 | 2 | 1356 | 65 |
| GC045 | *Escherichia coli* (colonies/100ml) | 6720 | 1380 | 13000 | 70 | 51700 | 28 |

**Table B–8** Storm event summary statistics for site GM060 (N = number of events).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| GM060 | $PO_4$-P (mg/L) | 0.320 | 0.313 | 0.265 | 0.002 | 0.864 | 69 |
| GM060 | Total-P (mg/L) | 0.51 | 0.49 | 0.38 | 0.02 | 1.49 | 69 |
| GM060 | $NH_3$-N (mg/L) | 0.096 | 0.049 | 0.175 | 0.007 | 1.35 | 69 |
| GM060 | $NO_2$-N + $NO_3$-N (mg/L) | 0.305 | 0.258 | 0.320 | 0.004 | 1.53 | 69 |
| GM060 | TKN (mg/L) | 1.34 | 1.27 | 0.79 | 0.10 | 4.61 | 69 |
| GM060 | TSS (mg/L) | 87 | 45 | 117 | 1 | 576 | 69 |
| GM060 | *Escherichia coli* (colonies/100ml) | 11000 | 733 | 23000 | 9 | 120000 | 36 |

**Table B–9** Storm event summary statistics for site HY060 (N = number of events).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| HY060 | $PO_4$-P (mg/L) | 0.021 | 0.012 | 0.023 | 0.000 | 0.081 | 71 |
| HY060 | Total-P (mg/L) | 0.14 | 0.10 | 0.12 | 0.01 | 0.74 | 71 |
| HY060 | $NH_3$-N (mg/L) | 0.036 | 0.030 | 0.028 | 0.007 | 0.157 | 71 |
| HY060 | $NO_2$-N + $NO_3$-N (mg/L) | 0.820 | 0.412 | 1.09 | 0.008 | 5.43 | 71 |
| HY060 | TKN (mg/L) | 0.83 | 0.75 | 0.59 | 0.08 | 3.04 | 71 |
| HY060 | TSS (mg/L) | 72 | 30 | 111 | 1 | 614 | 71 |
| HY060 | *Escherichia coli* (colonies/100ml) | 3530 | 579 | 7320 | 24 | 57900 | 131 |

**Table B–10** Storm event summary statistics for site IC020 (N = number of events).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| IC020 | $PO_4$-P (mg/L) | 0.608 | 0.587 | 0.414 | 0.021 | 1.86 | 78 |
| IC020 | Total-P (mg/L) | 1.19 | 1.21 | 0.60 | 0.11 | 2.77 | 78 |
| IC020 | $NH_3$-N (mg/L) | 0.235 | 0.132 | 0.263 | 0.018 | 1.39 | 78 |
| IC020 | $NO_2$-N + $NO_3$-N (mg/L) | 1.27 | 1.05 | 0.978 | 0.028 | 4.13 | 78 |
| IC020 | TKN (mg/L) | 3.50 | 3.40 | 1.47 | 0.72 | 7.33 | 78 |
| IC020 | TSS (mg/L) | 374 | 213 | 392 | 25 | 1750 | 78 |
| IC020 | *Escherichia coli* (colonies/100ml) | 30600 | 4380 | 64340 | 76 | 360000 | 94 |

**Table B–11** Storm event summary statistics for site LD040 (N = number of events).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| LD040 | $PO_4$-P (mg/L) | 0.527 | 0.541 | 0.271 | 0.032 | 1.247 | 61 |
| LD040 | Total-P (mg/L) | 1.08 | 1.11 | 0.49 | 0.26 | 2.05 | 62 |
| LD040 | $NH_3$-N (mg/L) | 0.401 | 0.148 | 0.738 | 0.01 | 3.93 | 61 |
| LD040 | $NO_2$-N + $NO_3$-N (mg/L) | 1.83 | 1.14 | 2.39 | 0.025 | 13.7 | 62 |
| LD040 | TKN (mg/L) | 3.75 | 3.37 | 1.99 | 0.72 | 9.81 | 62 |
| LD040 | TSS (mg/L) | 336 | 161 | 397 | 4 | 2148 | 62 |
| LD040 | *Escherichia coli* (colonies/100ml) | 29600 | 4640 | 49900 | 82 | 199000 | 32 |

**Table B–12** Storm event summary statistics for site LG060 (N = number of events).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| LG060 | $PO_4$-P (mg/L) | 0.205 | 0.145 | 0.187 | 0.018 | 0.737 | 46 |
| LG060 | Total-P (mg/L) | 0.72 | 0.40 | 0.74 | 0.05 | 3.28 | 46 |
| LG060 | $NH_3$-N (mg/L) | 0.165 | 0.077 | 0.182 | 0.010 | 0.762 | 46 |
| LG060 | $NO_2$-N + $NO_3$-N (mg/L) | 0.588 | 0.483 | 0.488 | 0.028 | 2.82 | 46 |
| LG060 | TKN (mg/L) | 3.10 | 2.07 | 2.81 | 0.10 | 13.2 | 46 |
| LG060 | TSS (mg/L) | 307 | 121 | 467 | 2 | 2140 | 46 |
| LG060 | *Escherichia coli* (colonies/100ml) | 2680 | 1120 | 3660 | 43 | 13300 | 29 |

**Table B–13** Storm event summary statistics for site NF009 (N = number of events).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| NF009 | $PO_4$-P (mg/L) | 0.319 | 0.327 | 0.146 | 0.002 | 0.773 | 64 |
| NF009 | Total-P (mg/L) | 0.72 | 0.62 | 0.52 | 0.16 | 3.81 | 62 |
| NF009 | $NH_3$-N (mg/L) | 0.243 | 0.118 | 0.382 | 0.007 | 2.64 | 64 |
| NF009 | $NO_2$-N + $NO_3$-N (mg/L) | 0.786 | 0.478 | 1.06 | 0.015 | 5.94 | 64 |
| NF009 | TKN (mg/L) | 2.48 | 2.13 | 1.41 | 0.36 | 9.92 | 62 |
| NF009 | TSS (mg/L) | 642 | 127 | 2050 | 13 | 12300 | 64 |
| NF009 | *Escherichia coli* (colonies/100ml) | 7900 | 3650 | 11100 | 214 | 48800 | 24 |

**Table B–14** Storm event summary statistics for site NF020 (N = number of events).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| NF020 | $PO_4$-P (mg/L) | 0.931 | 0.841 | 0.651 | 0.028 | 3.82 | 74 |
| NF020 | Total-P (mg/L) | 2.13 | 1.78 | 1.57 | 0.45 | 8.40 | 74 |
| NF020 | $NH_3$-N (mg/L) | 0.345 | 0.186 | 0.433 | 0.019 | 2.02 | 74 |
| NF020 | $NO_2$-N + $NO_3$-N (mg/L) | 1.16 | 0.856 | 0.820 | 0.261 | 4.05 | 74 |
| NF020 | TKN (mg/L) | 5.84 | 4.36 | 4.51 | 1.39 | 26.0 | 74 |
| NF020 | TSS (mg/L) | 779 | 351 | 1782 | 16 | 14900 | 74 |
| NF020 | *Escherichia coli* (colonies/100ml) | 44800 | 11800 | 69100 | 125 | 242000 | 63 |

**Table B–15** Storm event summary statistics for site NF050 (N = number of events).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| NF050 | $PO_4$-P (mg/L) | 0.454 | 0.447 | 0.231 | 0.099 | 1.34 | 75 |
| NF050 | Total-P (mg/L) | 0.84 | 0.78 | 0.40 | 0.13 | 2.13 | 75 |
| NF050 | $NH_3$-N (mg/L) | 0.168 | 0.115 | 0.161 | 0.010 | 0.746 | 75 |
| NF050 | $NO_2$-N + $NO_3$-N (mg/L) | 0.598 | 0.421 | 0.628 | 0.021 | 4.11 | 75 |
| NF050 | TKN (mg/L) | 2.47 | 2.19 | 1.43 | 0.66 | 10.0 | 75 |
| NF050 | TSS (mg/L) | 175 | 86 | 283 | 4 | 1650 | 75 |
| NF050 | *Escherichia coli* (colonies/100ml) | 13700 | 2440 | 20500 | 166 | 64900 | 30 |

**Table B–16** Storm event summary statistics for site SC020 (N = number of events).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| SC020 | $PO_4$-P (mg/L) | 0.167 | 0.107 | 0.176 | 0.006 | 0.862 | 80 |
| SC020 | Total-P (mg/L) | 0.41 | 0.34 | 0.35 | 0.08 | 2.06 | 81 |
| SC020 | $NH_3$-N (mg/L) | 0.109 | 0.063 | 0.130 | 0.018 | 0.661 | 81 |
| SC020 | $NO_2$-N + $NO_3$-N (mg/L) | 0.487 | 0.381 | 0.413 | 0.020 | 2.20 | 81 |
| SC020 | TKN (mg/L) | 1.50 | 1.36 | 0.90 | 0.25 | 5.30 | 81 |
| SC020 | TSS (mg/L) | 147 | 87 | 176 | 5 | 851 | 81 |
| SC020 | *Escherichia coli* (colonies/100ml) | 7910 | 1410 | 15300 | 87 | 77000 | 104 |

**Table B–17** Storm event summary statistics for site SF085 (N = number of events).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| SF085 | $PO_4$-P (mg/L) | 0.247 | 0.218 | 0.130 | 0.016 | 0.682 | 142 |
| SF085 | Total-P (mg/L) | 0.48 | 0.39 | 0.35 | 0.05 | 2.93 | 142 |
| SF085 | $NH_3$-N (mg/L) | 0.098 | 0.053 | 0.194 | 0.007 | 1.86 | 142 |
| SF085 | $NO_2$-N + $NO_3$-N (mg/L) | 0.387 | 0.306 | 0.295 | 0.007 | 1.55 | 142 |
| SF085 | TKN (mg/L) | 1.45 | 1.27 | 1.13 | 0.10 | 9.59 | 142 |
| SF085 | TSS (mg/L) | 119 | 37 | 224 | 2 | 1360 | 142 |
| SF085 | *Escherichia coli* (colonies/100ml) | 8360 | 1990 | 15800 | 42 | 77000 | 42 |

**Table B–18** Storm event summary statistics for site SP020 (N = number of events).

| Site | Constituent | Mean | Median | Std Dev. | Minimum | Maximum | N |
|---|---|---|---|---|---|---|---|
| SP020 | $PO_4$-P (mg/L) | 0.027 | 0.007 | 0.057 | 0.006 | 0.449 | 81 |
| SP020 | Total-P (mg/L) | 0.15 | 0.10 | 0.14 | 0.06 | 1.0 | 81 |
| SP020 | $NH_3$-N (mg/L) | 0.034 | 0.022 | 0.030 | 0.018 | 0.203 | 81 |
| SP020 | $NO_2$-N + $NO_3$-N (mg/L) | 0.084 | 0.042 | 0.092 | 0.028 | 0.531 | 81 |
| SP020 | TKN (mg/L) | 0.71 | 0.53 | 0.51 | 0.25 | 2.84 | 81 |
| SP020 | TSS (mg/L) | 82 | 25 | 137 | 5 | 729 | 81 |
| SP020 | *Escherichia coli* (colonies/100ml) | 8740 | 345 | 40700 | 45 | 242000 | 35 |

# APPENDIX C

# Record of Average Daily Flow for Each Stream Site

**Figure C–1** Average daily flow at AL020 for July1, 2001 through December 31, 2007.

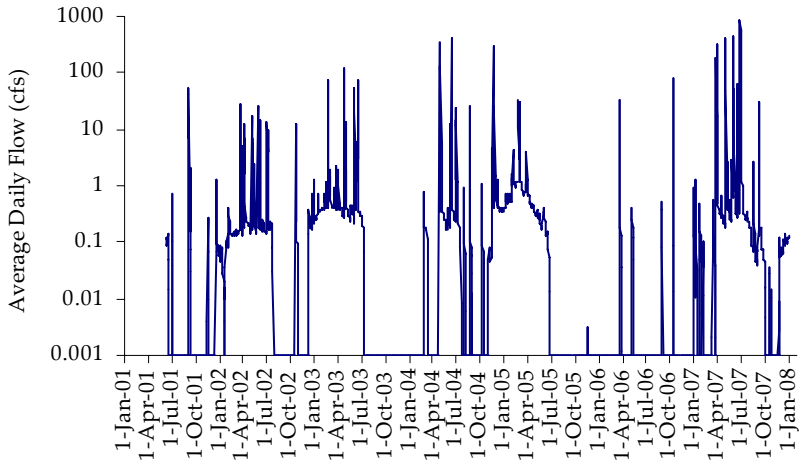



**Figure C–2** Average daily flow at DB035 for January 4, 2002 through December 31, 2007.

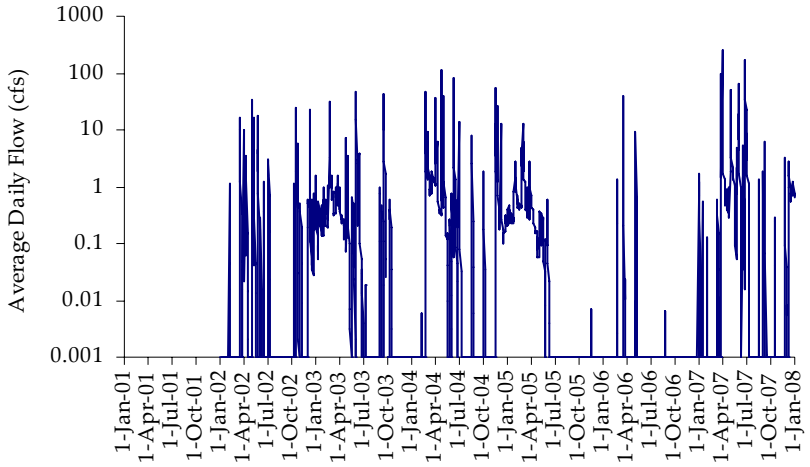


**Figure C–3** Average daily flow at DC040 for April 10, 2001 through December 31, 2007.

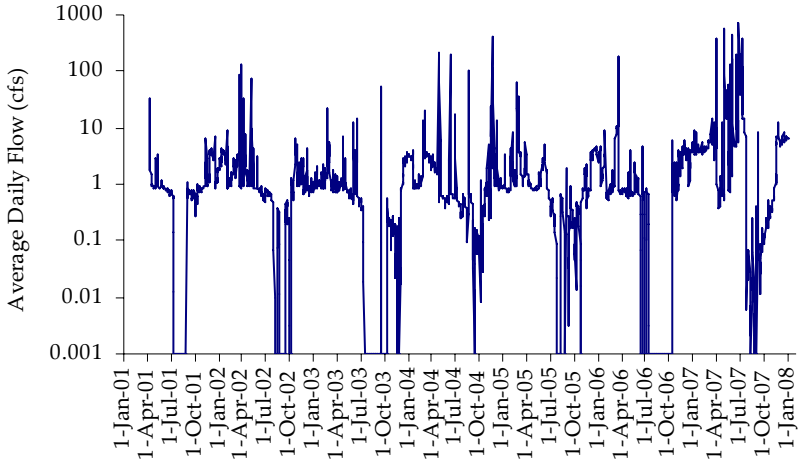



**Figure C–4** Average daily flow at GB020 for January 1, 2001 through December 31, 2007.

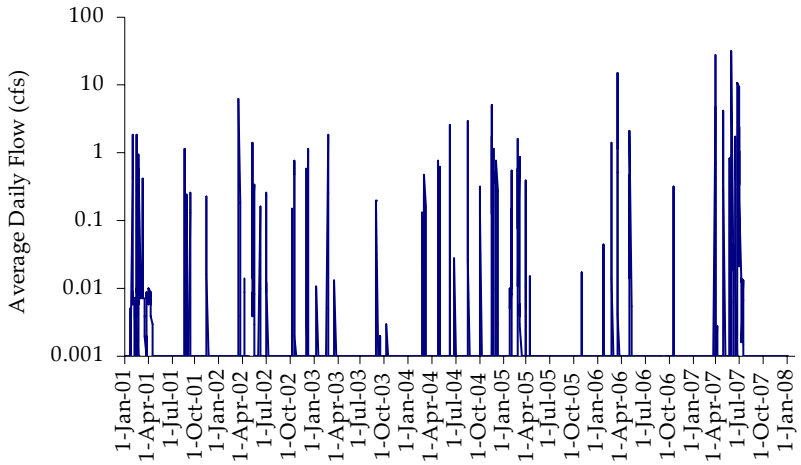


**Figure C–5** Average daily flow at GB025 for January 9, 2001 through June 8, 2007.

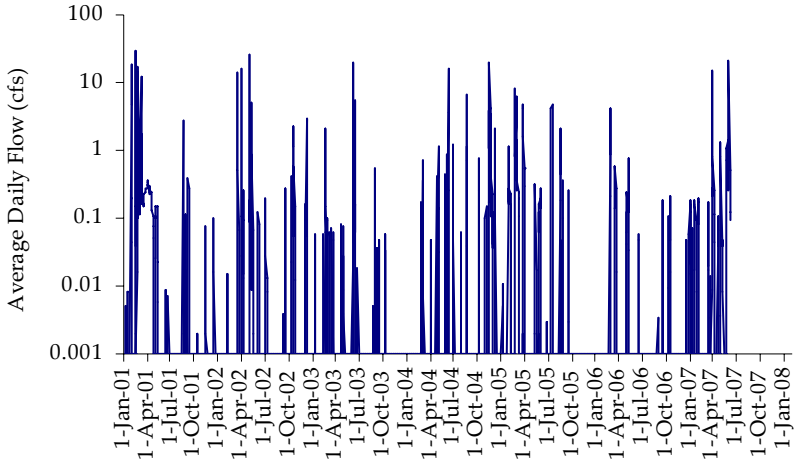



**Figure C–6** Average daily flow at GB040 for January 1, 2001 through June 8, 2007.

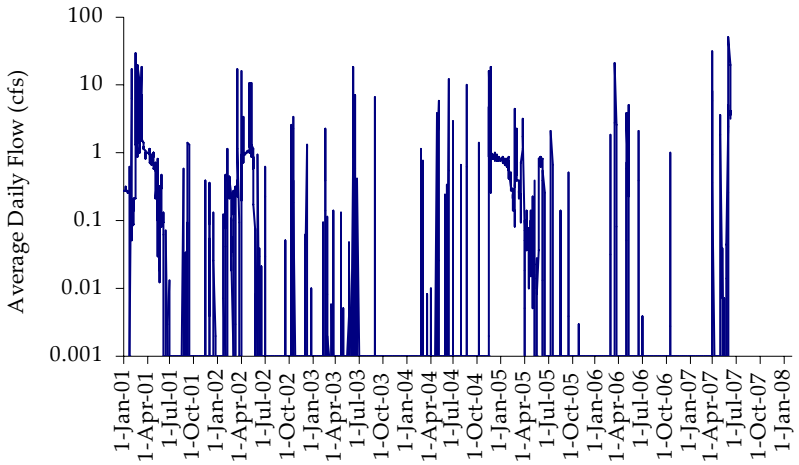


**Figure C–7** Average daily flow at GC045 for April 9, 2001 through December 31, 2007.

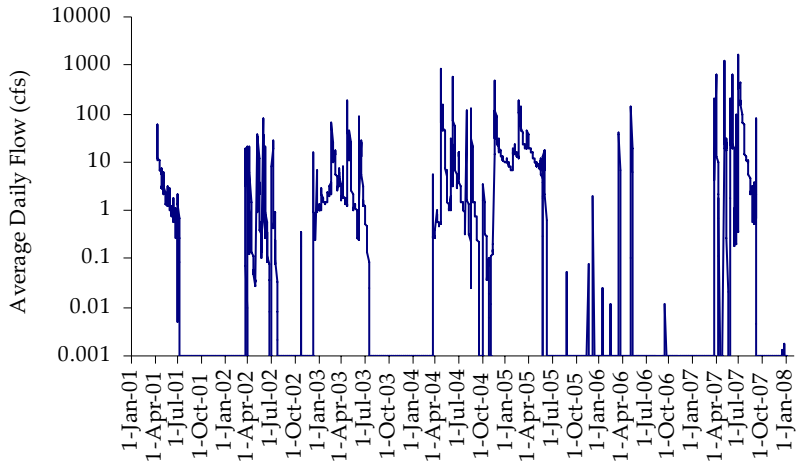



**Figure C–8** Average daily flow at GM060 for March 7, 2001 through December 31, 2007.

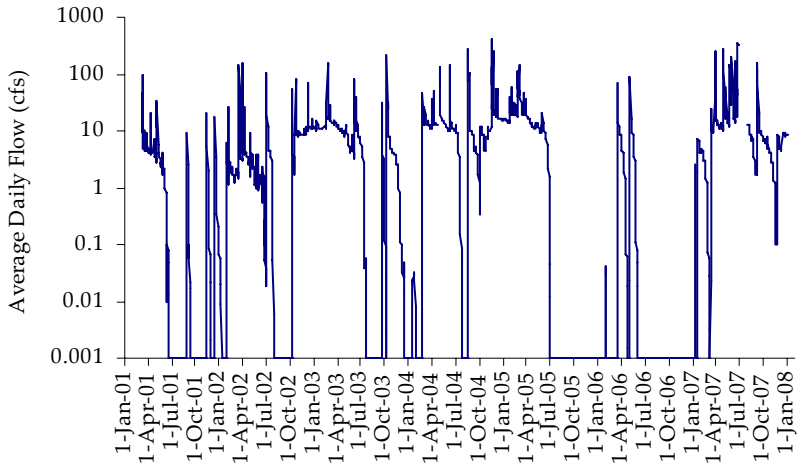


**Figure C–9** Average daily flow at HY060 for April 5, 2001 through December 31, 2007.

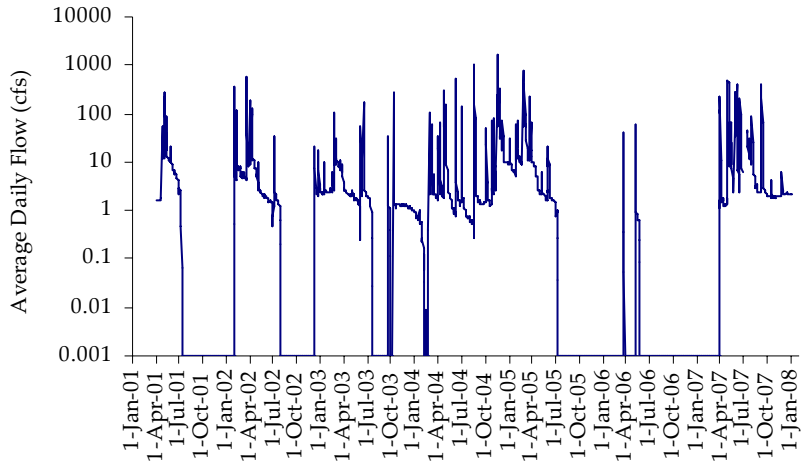



**Figure C–10** Average daily flow at IC020 for January 24, 2001 through December 31, 2007.

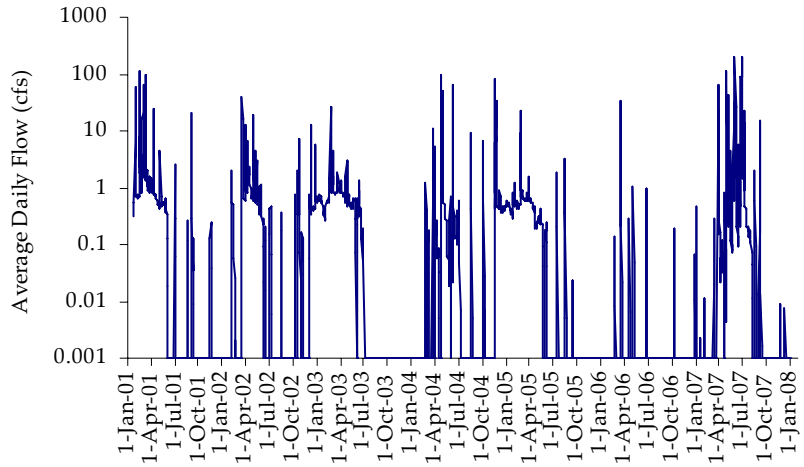


**Figure C–11** Average daily flow at LD040 for June 6, 2001 through December 31, 2007.

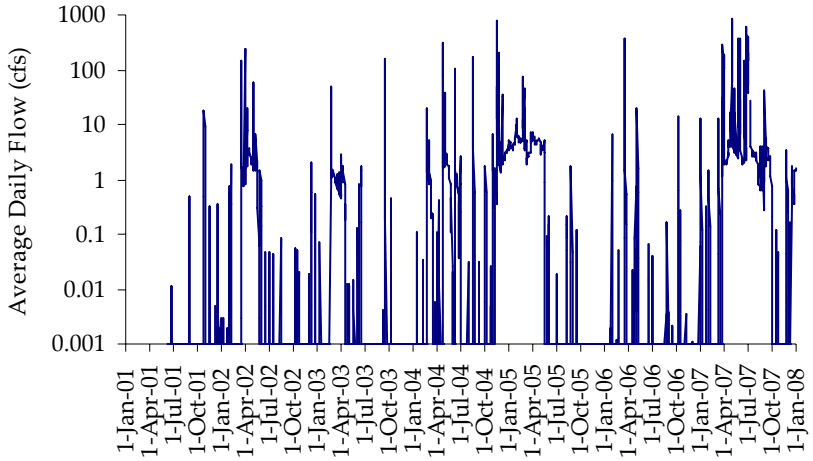



**Figure C–12** Average daily flow at LG060 for June 6, 2001 through December 31, 2007.

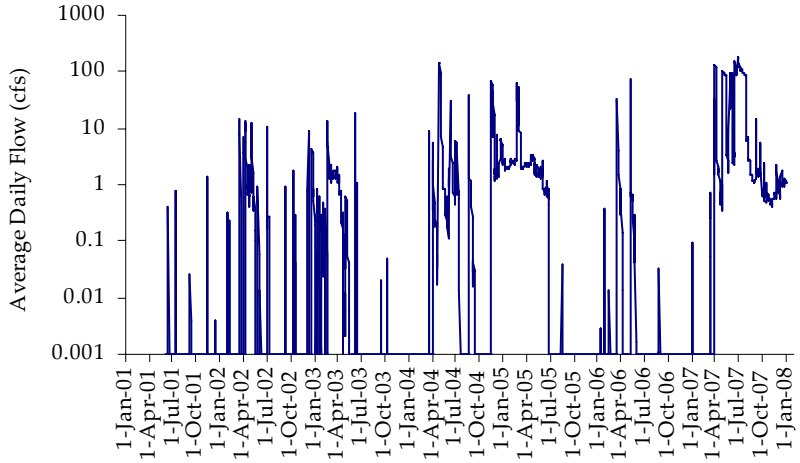
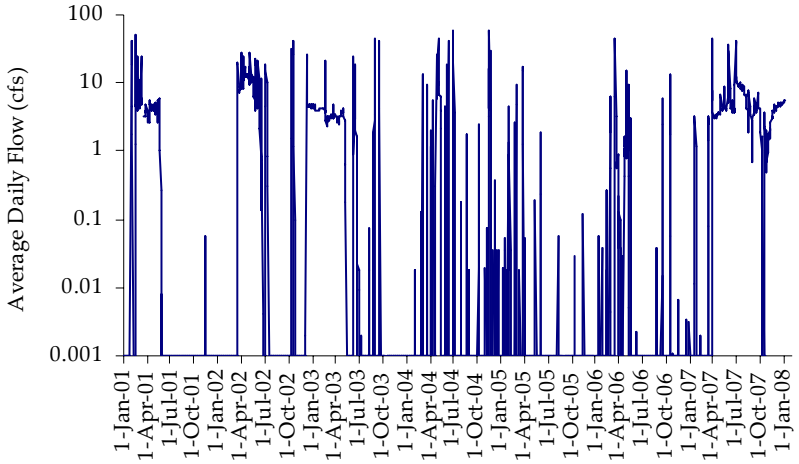


**Figure C–13** Average daily flow at NF009 for January 1, 2001 through December 31, 2007*.




*Site NF009 was relocated on February 15, 2006 due to bridge construction on the county road and as a result flow data from February 15, 2006 through December 31, 2007 are provisional and subject to change.

**Figure C–14** Average daily flow at NF020 for January 1, 2001 through December 31, 2007.

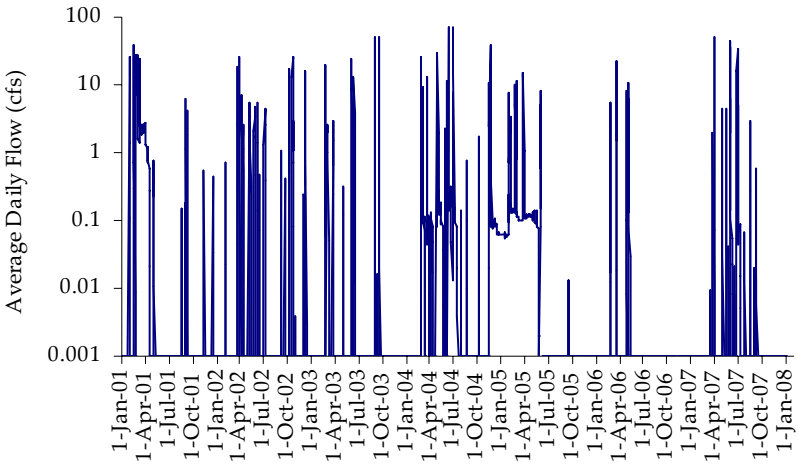


**Figure C–15** Average daily flow at NF050 for April 26, 2001 through December 31, 2007. Breaks in the hydrograph indicate missing data.

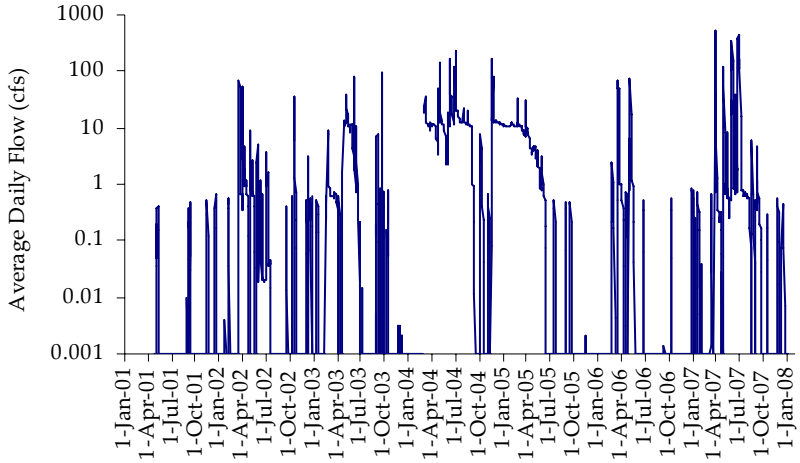



**Figure C–16** Average daily flow at SC020 for March 20, 2001 through December 31, 2007.

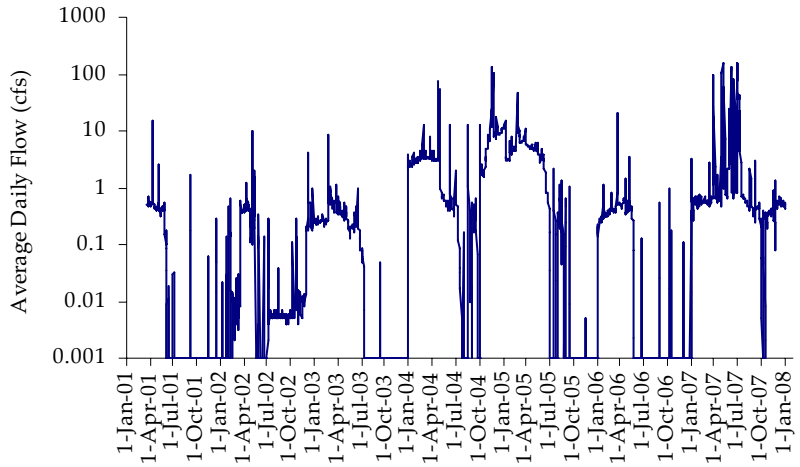


**Figure C–17** Average daily flow at SF085 for May 1, 2001 through December 31, 2007.

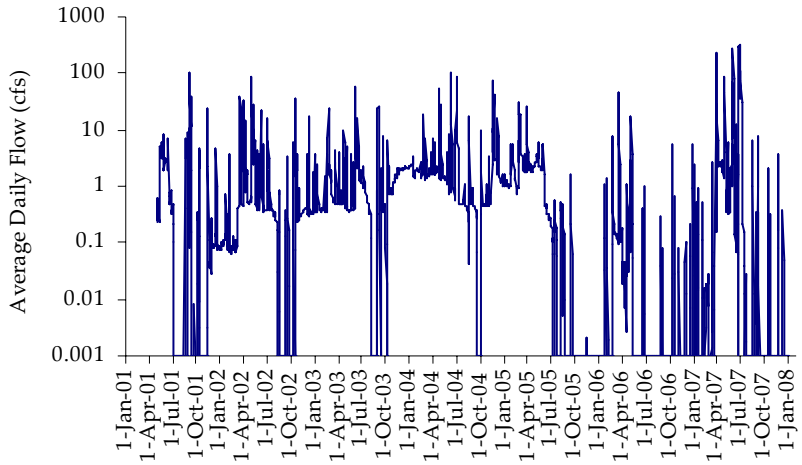
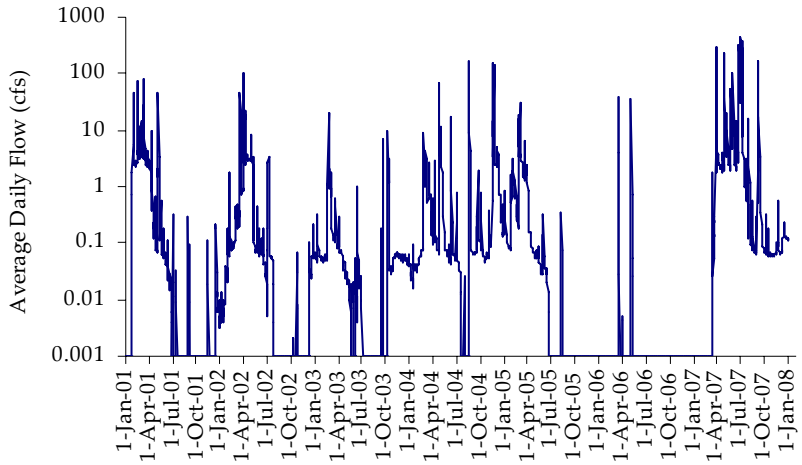



**Figure C–18** Average daily flow at SP020 for January 3, 2001 through December 31, 2007.



# APPENDIX D

# LOWESS Regression Plots of Bacteria Concentration versus Flow

All data represent routine or storm grab samples collected between January 2001 and December 31, 2007. Exact dates will vary by site based on monitoring history. Dashed lines in plots represent LOWESS regression results.

**Figure D–1** Relationship of bacteria concentration to flow for AL020.

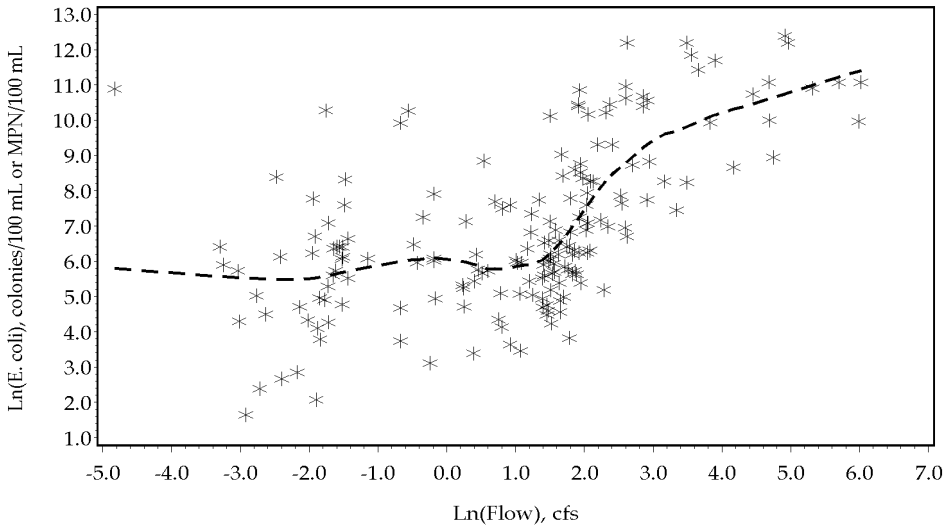


**Figure D–2** Relationship of bacteria concentration to flow for DB035.

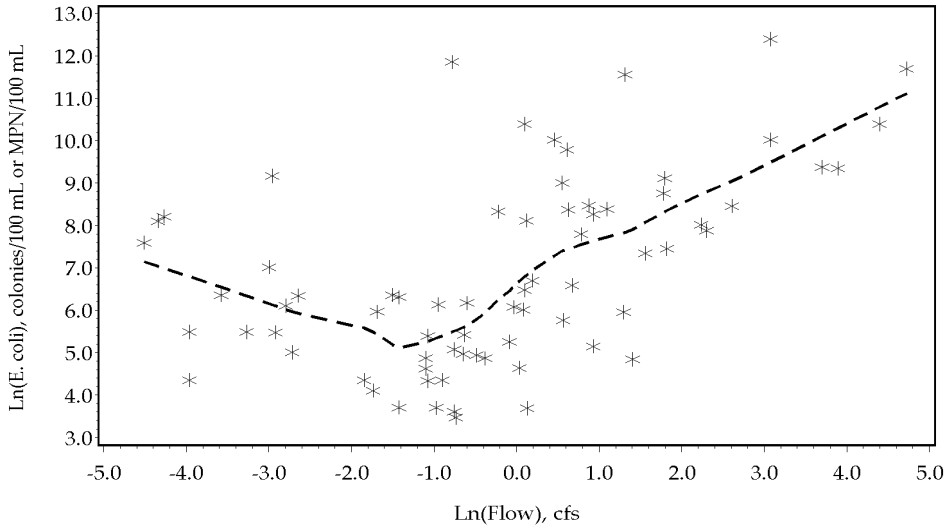



**Figure D–3** Relationship of bacteria concentration to flow for DC040.

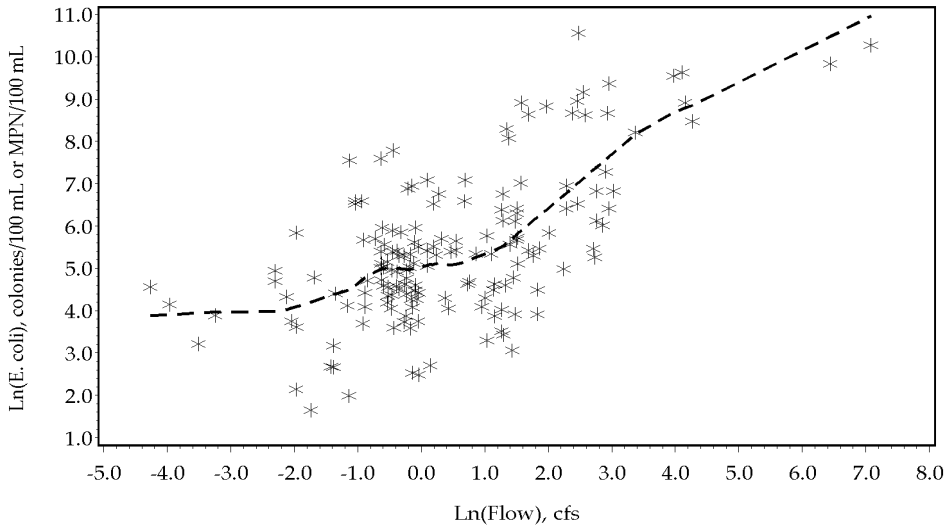


**Figure D–4** Relationship of bacteria concentration to flow for GB020.

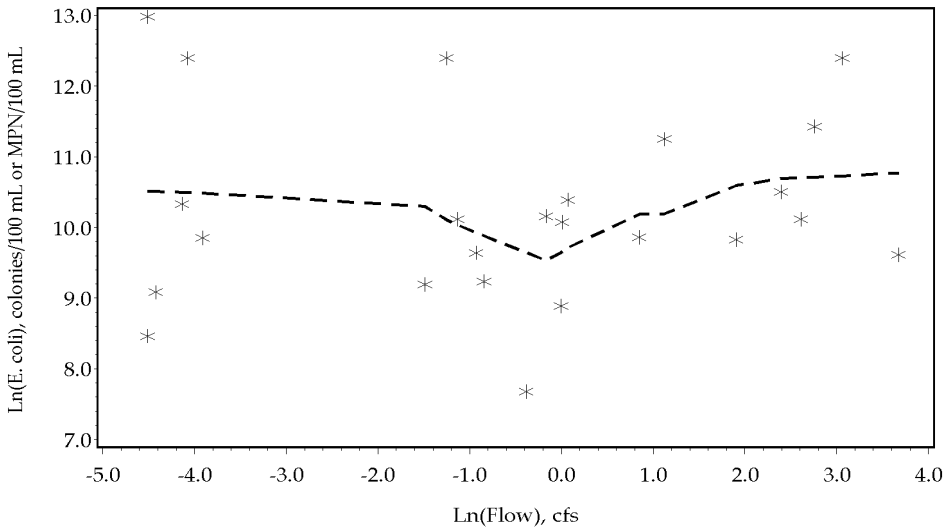



**Figure D–5** Relationship of bacteria concentration to flow for GB040.

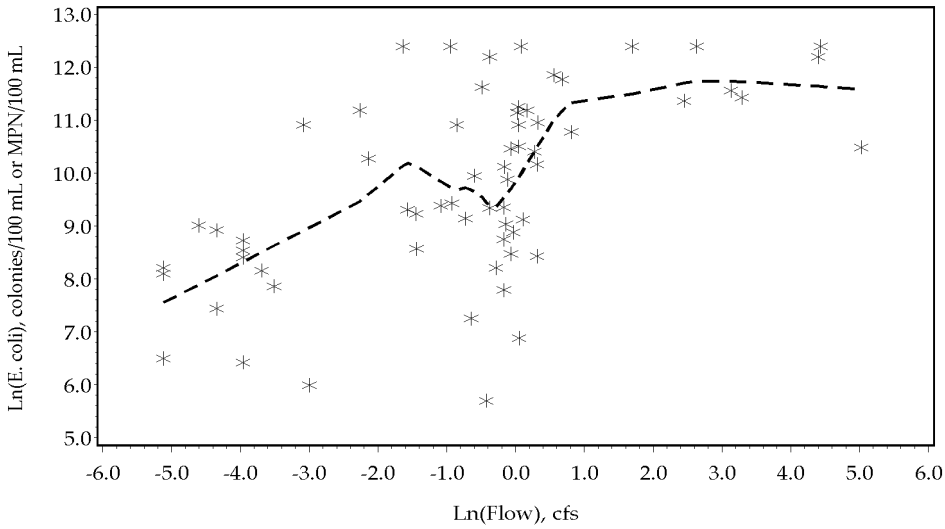


**Figure D–6** Relationship of bacteria concentration to flow for GC045.

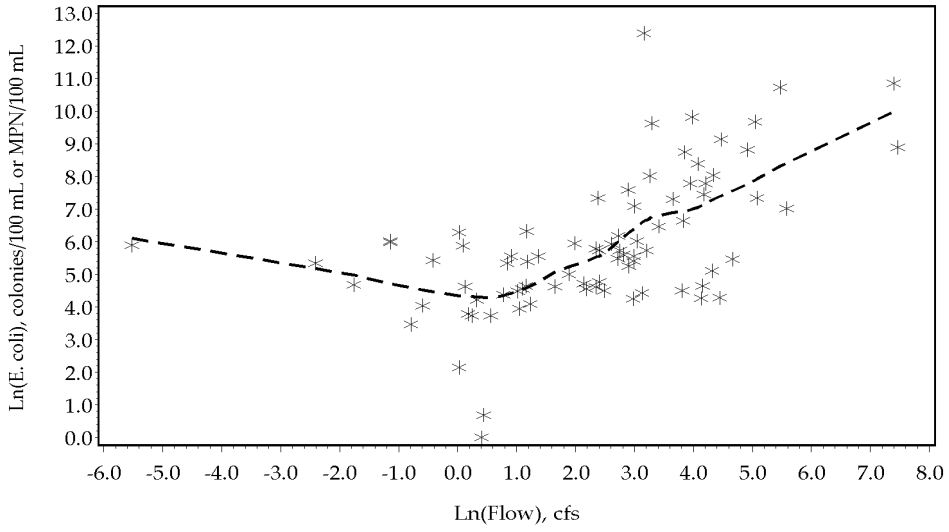



**Figure D–7** Relationship of bacteria concentration to flow for GM060.

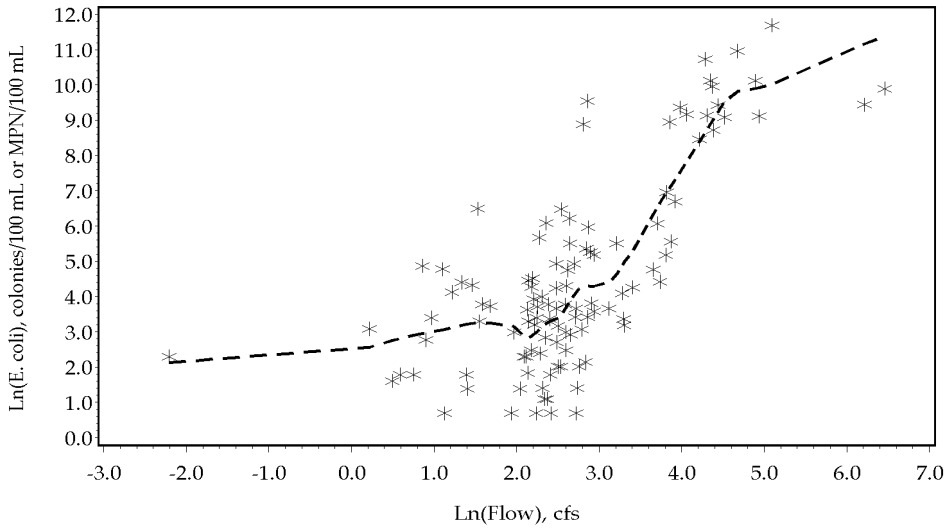


**Figure D–8** Relationship of bacteria concentration to flow for HY060.

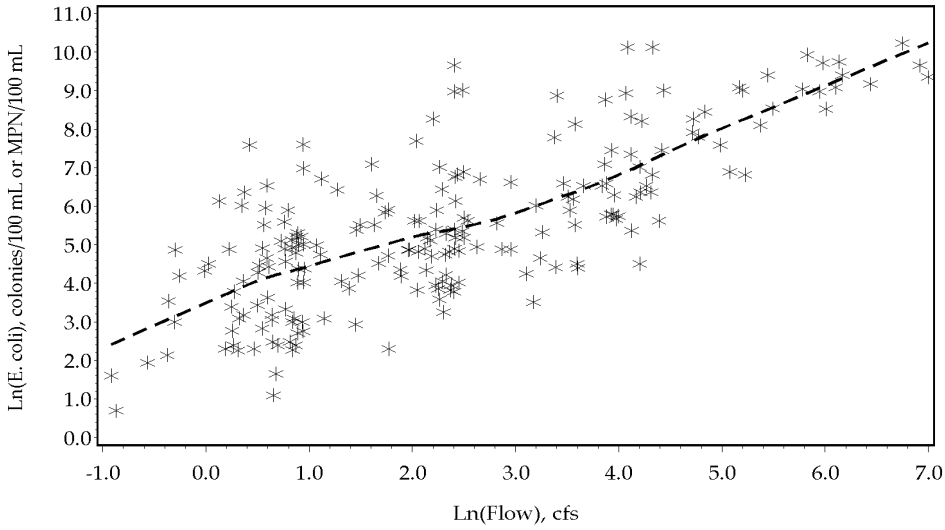



**Figure D–9** Relationship of bacteria concentration to flow for IC020.

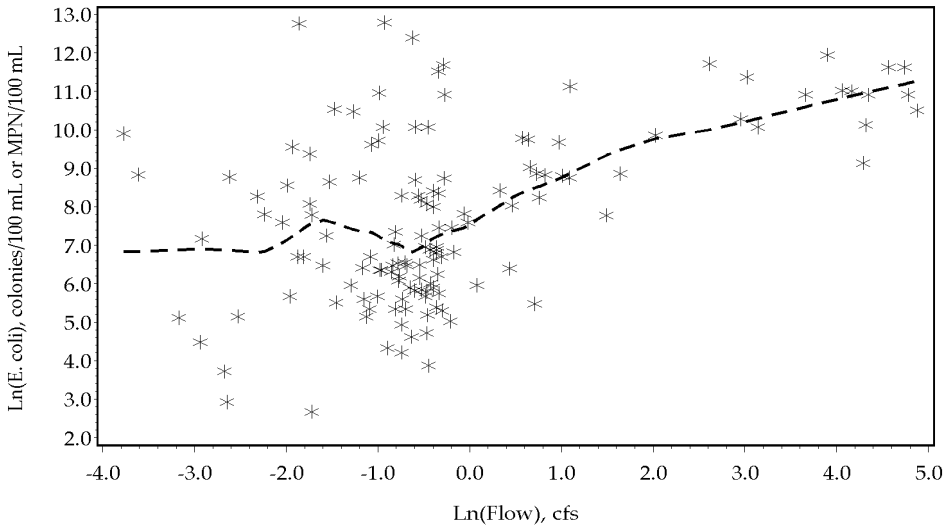


**Figure D–10** Relationship of bacteria concentration to flow for LD040.

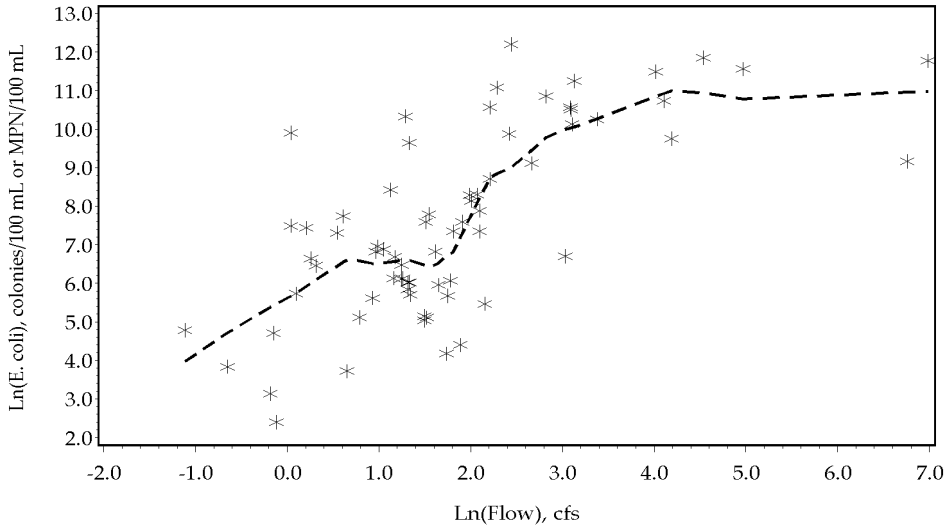



**Figure D–11** Relationship of bacteria concentration to flow for LG060.

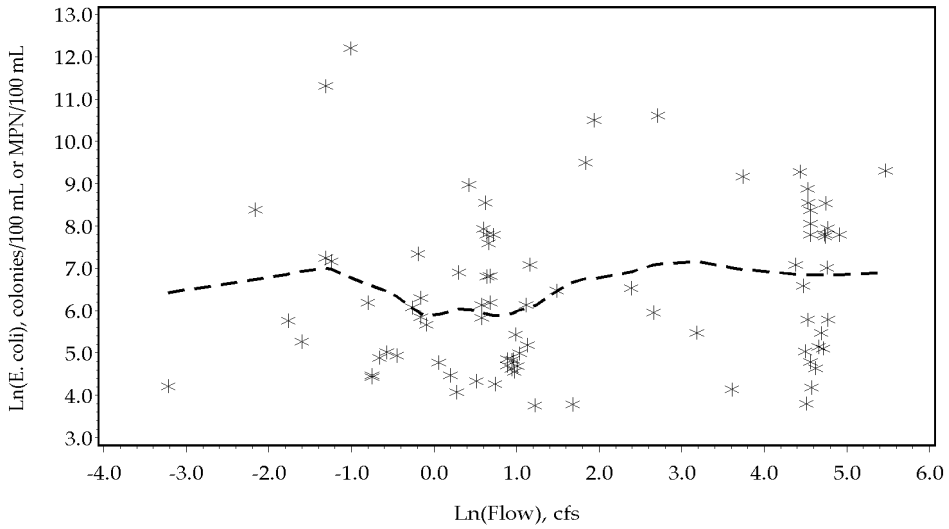


**Figure D–12** Relationship of bacteria concentration to flow for NF020.

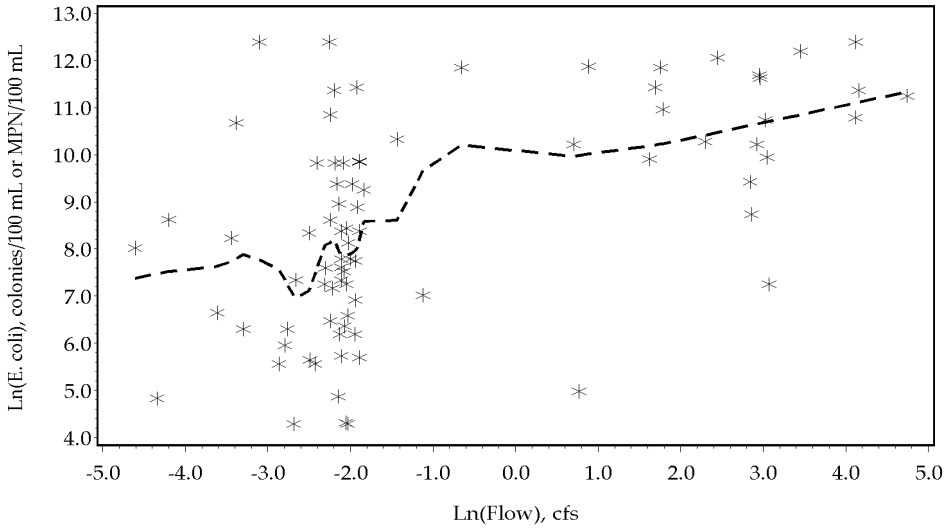



**Figure D–13** Relationship of bacteria concentration to flow for NF050.

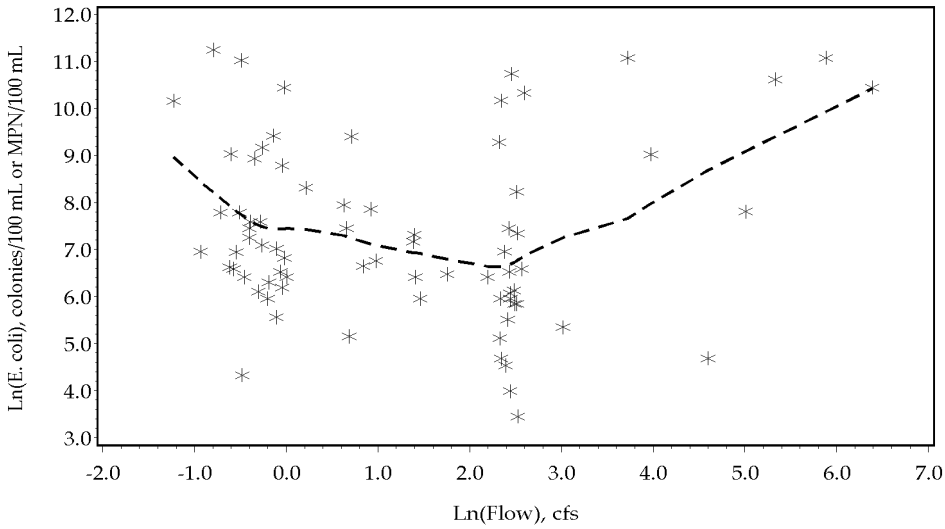


**Figure D–14** Relationship of bacteria concentration to flow for SC020.

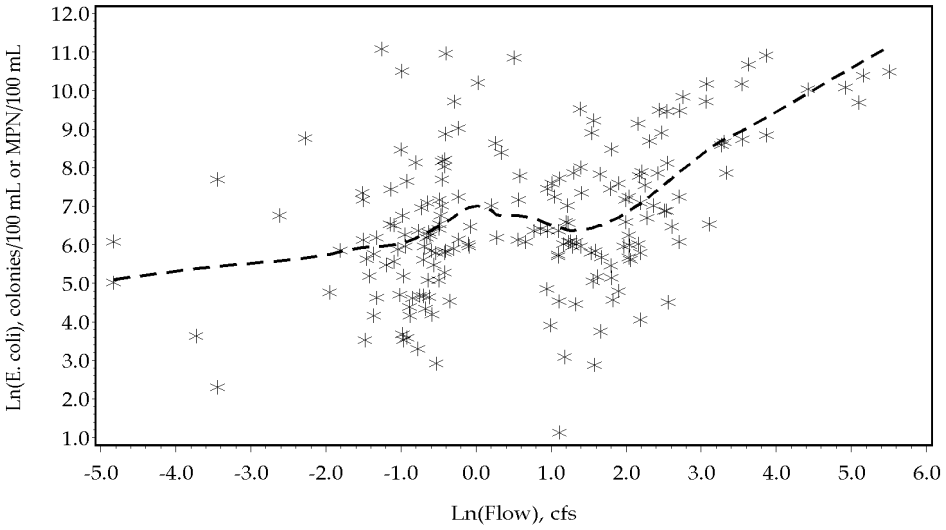



**Figure D–15** Relationship of bacteria concentration to flow for SF085.

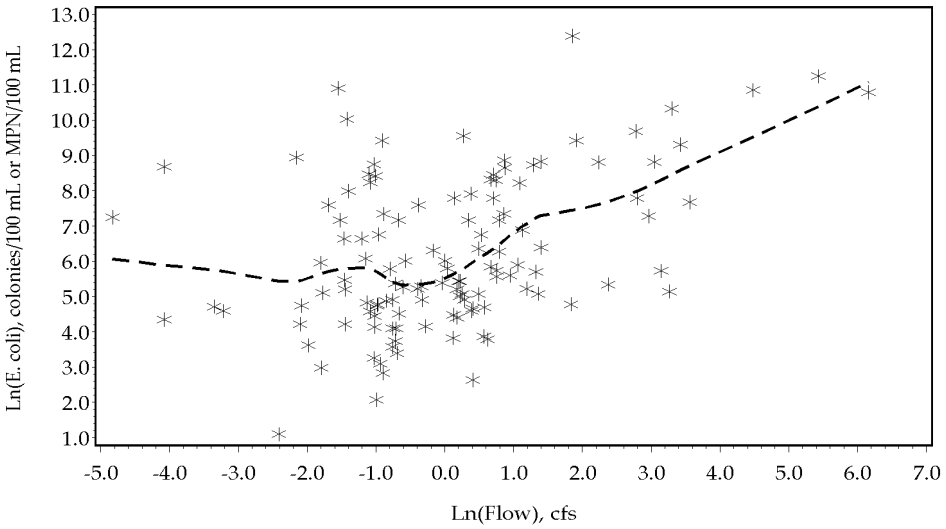


**Figure D–16** Relationship of bacteria concentration to flow for SP020.