TIAER
PR 9911

EXISTING NUTRIENT SOURCES AND CONTRIBUTIONS TO THE BOSQUE RIVER WATERSHED

Anne McFarland and Larry Hauck

September 1999

Texas Institute for Applied Environmental Research • Tarleton State University
Box T0410, Tarleton Station • Stephenville, Texas 76402 • (254) 968-9567 • Fax (254) 968-9568

EXECUTIVE SUMMARY

Over about a two and a half-year period (November 1, 1995 – March 30, 1998), flow and nutrients were monitored consistently at 17 sites in the Bosque River watershed. Drainage areas above sampling sites differed in the percent of dairy waste application fields, row crop (corn, grain sorghum, soybeans and cotton), non-row crop (forage sorghum and winter wheat), improved pasture (primarily coastal bermudagrass fields), wood/range, and urban land area. A statistical approach was used to develop nutrient export coefficients of orthophosphate-phosphorus (PO_4-P), total phosphorus (TP), and total nitrogen (TN) for the major land uses in these mixed land-use drainage areas. Nutrient export coefficients represent the amount of nonpoint source loading associated with a given land use per unit area for a specified length of time, such as pounds TP per acre per year. Of the major land uses in the Bosque River watershed, the largest export coefficients for PO_4-P and TP were associated with dairy waste application fields (3.08 lbs PO_4-P/acre/yr and 5.81 lbs TP/arce/yr) followed by urban (0.98 lbs PO_4-P/acre/yr and 2.73 lbs TP/acre/yr), pasture/cropland (0.14 lbs PO_4-P/acre/yr and 0.70 lbs TP/acre/yr), then wood/range (0.07 lbs PO_4-P/acre/yr and 0.31 lbs TP/acre/yr). The largest TN export coefficients were associated with row-crop areas (19.0 lbs TN/acre/yr) followed by dairy waste application fields (12.3 lbs TN/acre/yr), urban (11.5 lbs TN/acre/yr), pasture/non-row crop fields (7.2 lbs TN/acre/yr) then wood/range (2.2 lbs TN/acre/yr).

An empirical model was developed to assess nutrient contribution by source using the developed export coefficients for nonpoint sources and information from the eight permitted municipal wastewater treatment plants within the watershed for point source loadings. This model was verified by comparing estimated loadings to measured loadings at four stream sites located along the North Bosque River. These four sites were not included in the development of the land-use nutrient export coefficients to allow an independent verification of the model. Monte Carlo sampling techniques were applied to the variance associated with the derived nutrient export coefficients to provide an uncertainty analysis for nutrient loads by source for the Bosque River watershed and for selected points within the watershed.

The largest loadings of PO_4-P and TP contributing to the Bosque River watershed were from dairy waste application fields and wood/rangeland, while the largest loadings of TN were associated with row-crop fields. Dairy waste application fields comprise about 2 percent of the total watershed area and were associated with 35 $\pm$ 4 percent PO_4-P, 21 $\pm$ 3 percent TP and 5 $\pm$ 2 percent TN loadings to the watershed. Wood/range comprise 63 percent of the watershed area and were associated with 22 $\pm$ 5 percent PO_4-P, 31 $\pm$ 6 percent TP and 22 $\pm$ 12 percent TN loadings to the watershed. Row-crop agriculture is associated with 15 percent of the watershed drainage area and was associated with 11 $\pm$ 1 percent PO_4-P, 17 $\pm$ 2 percent TP and 49 $\pm$ 10 percent TN loadings. Most dairy waste application fields in the watershed are found in the upper portion of the North Bosque River subwatershed, while most row-crop fields are found in the southern portion of the Bosque River watershed within the Hog Creek, Middle Bosque and South Bosque River subwatersheds. The derived nutrient export coefficients and, thus, the source-contribution model results are specific to the time period November 1, 1995 through March 30, 1998 and care should be taken in extrapolating these results to other timeframes or watersheds.

ACKNOWLEDGMENTS

Funding sources for this study include the United States Department of Agriculture - Natural Resources Conservation Service, the Clean Rivers Program of the Texas Natural Resource Conservation Commission, the United States Environmental Protection Agency and the State of Texas. The authors acknowledge the support of landowners that allowed access to their property for in-stream monitoring. Without the willing cooperation of these individuals, this study would not have been possible. The authors would also like to acknowledge the dedicated work of the many field personnel and laboratory chemists involved with the monitoring program, particularly since rain often falls on weekends requiring staff to be on call seven days a week.

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INTRODUCTION

The Bosque River watershed of north-central Texas is defined by the drainage area to Lake Waco (Figure 1). This drainage area includes the North Bosque River, Hog Creek, Middle Bosque River, and South Bosque River as major tributaries to Lake Waco as well as a few minor tributaries representing small drainage areas near the reservoir.

The City of Waco constructed Lake Waco in 1929 as a municipal water supply. The reservoir was enlarged to its present size in 1964 by the U.S. Army Corps of Engineers for flood control, conservation storage, and recreation. Lake Waco is formed by a rolled earthfill dam and provides the public water supply for Waco and surrounding communities with a service population of approximately 140,000. The Brazos River Authority and the City of Waco jointly hold the rights to water in the conservation storage of the reservoir, which was built to contain about 152,00 acre-feet of water at the spillway elevation (Wyrick, 1978). Lake Waco has a surface area of about 7,270 acres and a normal pool elevation of about 455 feet (TNRCC, 1996). The designated uses for Lake Waco (segment 1225) are contact recreation, high aquatic life and public water supply with agricultural operations thought to be the major contributors of nonpoint source pollution in the reservoir watershed (TNRCC, 1996).

Point and nonpoint sources contribute nutrient loadings to the Bosque River watershed. In general terms, point sources represent nutrients that can be traced to a single point of discharge, such as a pipe or culvert, while nonpoint sources represent nutrients that cannot be traced to a specific point. There are eight permitted wastewater treatment plants (WWTPs) representing permitted point source discharges within the Bosque River watershed (Table 1). Of the eight WWTPs in the Bosque River watershed, only Stephenville and McGregor require advanced wastewater treatment for the attainment of stream standards (TNRCC, 1996). The Brazos River Authority and Texas Institute for Applied Environmental Research (TIAER) have collected grab samples of the effluent from all eight WWTP since January 1996 on a monthly or bi-weekly basis. Combined with the monthly discharge information reported to the TNRCC by each WWTP this nutrient data can be used to estimate nutrient loadings from the point sources within the Bosque River watershed.

Figure 1. Bosque River watershed.

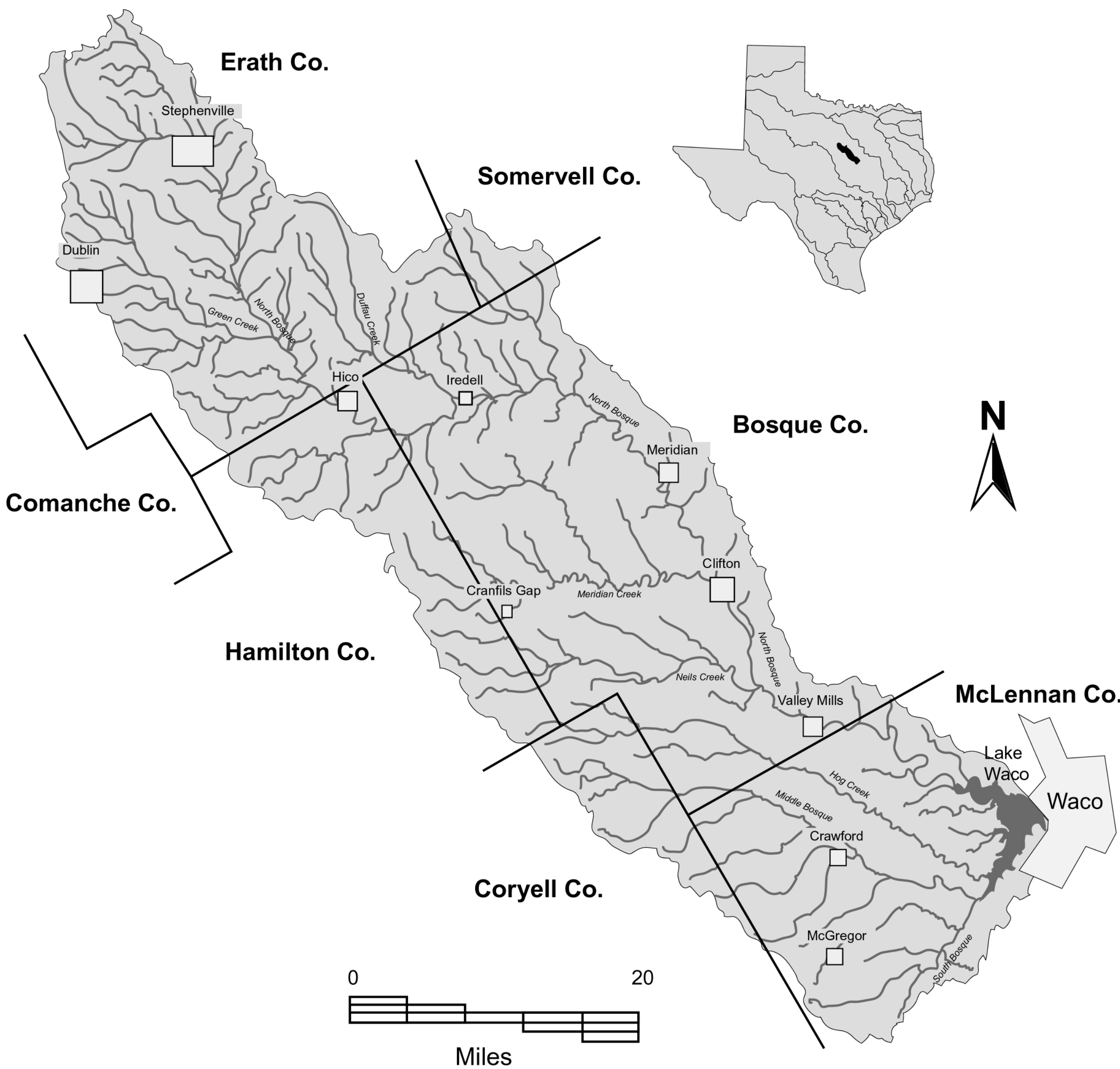


Table 1. Point sources in the Bosque River watershed as represented by the eight permitted wastewater treatment plants (WWTPs) within the watershed. Discharge in million gallons per day (MGD).

WWTP	Permitted Daily Average Discharge (MGD)	Major Receiving Stream
Stephenville†	3.000	North Bosque River
Hico	0.200	North Bosque River
Iredell	0.050	North Bosque River
Meridian	0.450	North Bosque River
Clifton	0.400	North Bosque River
Valley Mills	0.360	North Bosque River
Crawford	0.026	Middle Bosque River
McGregor†	1.100	South Bosque River

†Discharge limitation for ammonia (NH_3-N).

Nonpoint source nutrient loadings come from the variety of land uses within the watershed. The North Bosque River, with its headwaters located about 10 miles northwest of Stephenville, Texas represents about 74 percent of the drainage area for Lake Waco (Figure 2). In 1990, the North Bosque River watershed was identified as an impacted watershed due to nonpoint source pollution (Texas Water Commission and Texas State Soil and Water Conservation Board, 1991) and has been on the Texas 303(d) list of impaired waters since 1992. The prominence of the dairy industry in the upper portion of the North Bosque River drainage has been identified as major contributor of nonpoint source nutrients within the upper North Bosque River watershed (McFarland and Hauck, 1998a). Noticeable eutrophication of several small water bodies within the drainage of the North Bosque River and elevated nutrient concentrations in tributaries to the North Bosque River support the need for a reduction in nutrient loadings to the North Bosque River (Brazos River Authority, 1994; McFarland and Hauck, 1997a, 1997b).

In a recent State of Texas Water Quality Inventory (TNRCC, 1996), several comments address the water quality of classified stream segments along the North Bosque River (Figure 3). Segment 1226 is defined as the North Bosque River from a point 328 feet upstream of Farm-to-Market Road 185 in McLennan County to a point immediately above the confluence of Indian Creek in Erath County. Segment 1255 is defined as the North Bosque River from a point immediately above its confluence with Indian Creek to the confluence of the North and South Forks of the North Bosque River. Nonpoint source loadings are associated with elevated nutrient and fecal coliform levels within segments 1226

Figure 2. Major subwatersheds of the Bosque River watershed.

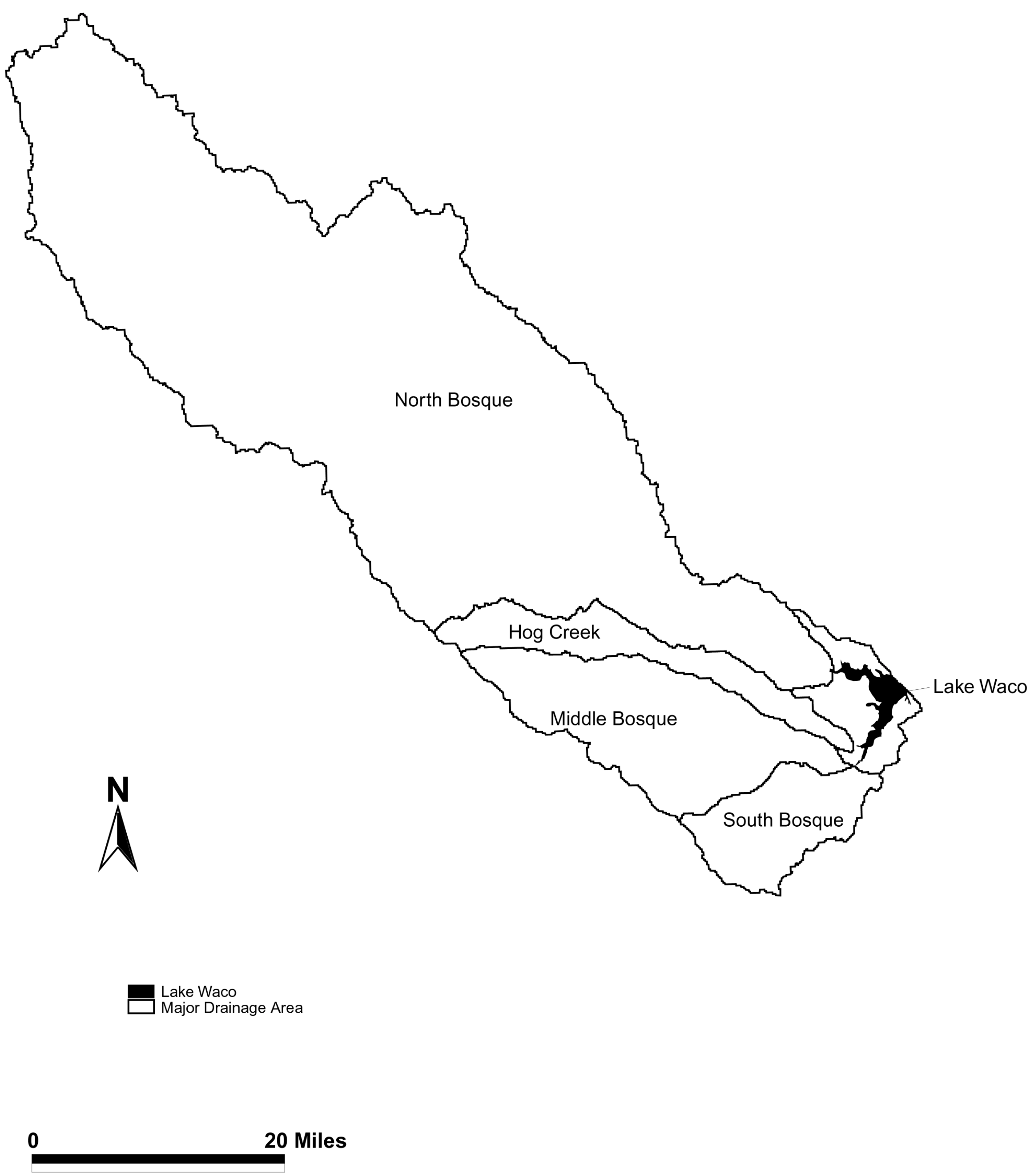
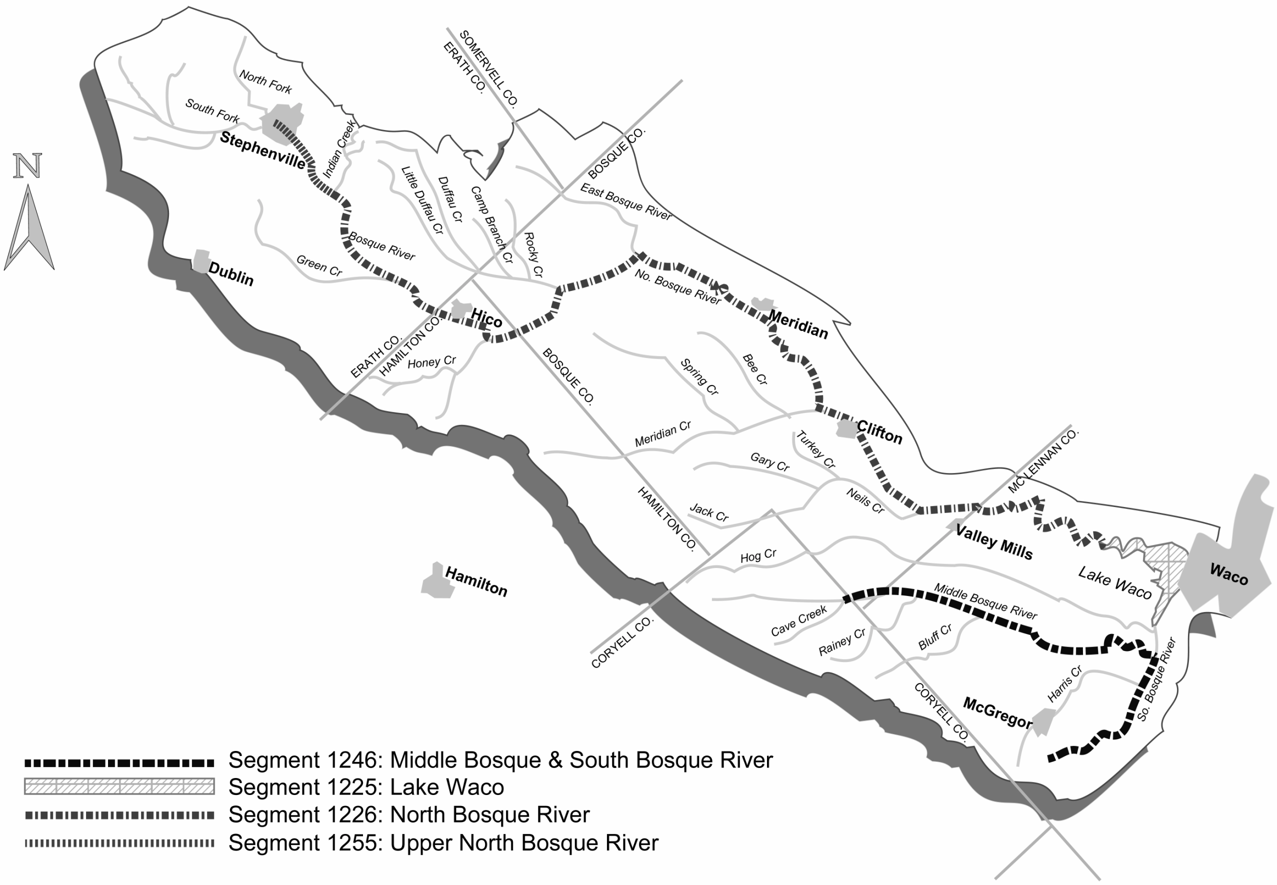


Figure 3. Designated segments and water uses within the Bosque River watershed



and 1225 and are described as the most serious threat to meeting the designated of these segments. The State of Texas 1999 303(d) list contains the two North Bosque River segments, 1226 and 1255, and a draft schedule of total maximum daily load (TMDL) development for these segments (TNRCC, 1999). Nutrients are the focus of this TMDL effort due to the role of nutrients in promoting excessive algae growth as indicated by elevated chlorophyll-α levels throughout segments 1226 and 1255 (TNRCC, 1999).

Of the other designated segments within the Bosque River watershed, nonpoint source pollution loadings from agricultural operations are noted as concerns for segment 1246, the Middle Bosque/South Bosque River, and for segment 1225, Lake Waco. Elevated nitrogen levels are also noted for segment 1246. Segment 1246 includes those portions of the Middle and South Bosque Rivers located in McLennan County as well as a small portion of the Middle Bosque River in Coryell County up to the confluence with Cave Creek (Figure 3).

Estimating nutrient loading from nonpoint sources is confounded by the fact that they originate from widespread areas that are diffuse by nature and often only contribute following rainfall. Land-use export coefficients are one tool often used to estimate nutrient loadings from nonpoint sources (Loehr *et al.*, 1989). A nutrient export coefficient represents the amount of a nutrient transported from a given land use per unit area per unit time. Export coefficients are generally expressed in units, such as lbs/acre/yr, or on a per capita basis as a function of population density (lbs/person/yr). Often generalized land-use export coefficients are used in watershed management planning rather than direct monitoring of land-use loadings due to the high cost and labor involved in direct monitoring. Recently released watershed loading models, such as WATERSHEDSS (WATER, Soil, and Hydro-Environmental Decision Support System) developed by the North Carolina State University Water Quality Group (Osmond *et al.*, 1997) and BASINS (Better Assessment Science Integrating Point and Nonpoint Sources) developed by the U.S. Environmental Protection Agency (1998), present generalized export coefficients for many land uses, but allow the user to input regionally specific coefficient values when available. Regionally specific export coefficients are recommended, because precipitation, soils, and management practices associated with specific land uses often vary between regions leading to very different coefficient values for the same land use at different locations (Clesceri, *et al*., 1986).

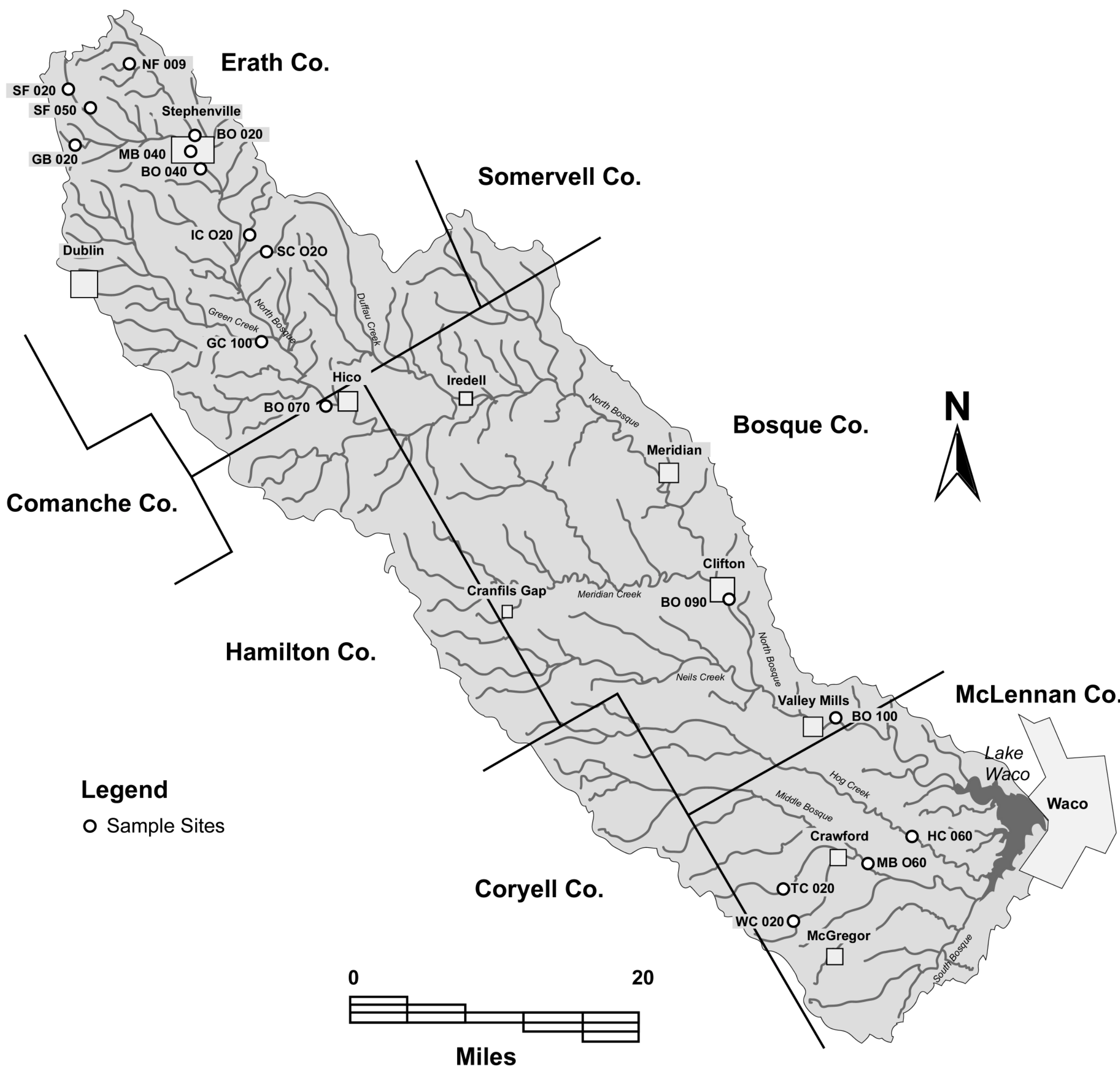
In early 1991, TIAER began monitoring stream water quality in the drainage area of the North Bosque River above Hico, Texas. While most early monitoring consisted of grab samples, a number of automatic samplers were installed from late 1992 through 1993 in the upper North Bosque River watershed (McFarland and Hauck, 1995). In the fall of 1995, TIAER's monitoring network was expanded to include sampling sites throughout the Bosque River watershed (McFarland and Hauck, 1998a). While the monitoring network has changed over the years with regards to the number of sites and specific site locations, a largely consistent record from November 1995 through March 1998 was available at 17 automatic sampling sites representing locations throughout the Bosque River watershed (Figure 4). These 17 stream sampling sites represent the best available watershed specific monitoring data for estimating nutrient export coefficients for the various land uses within the Bosque River watershed.

The automatic samplers at these sites are programmed to collect stormwater samples and continuously measure water level. Site specific stage-discharge relationships are developed from manual measurements of flow and used to derive streamflow from the water level data. Routine grab sampling at monthly or bi-weekly intervals complements the stormwater monitoring to provide characterization of base flow water quality conditions. Stormwater and routine grab samples are analyzed for orthophosphate-phosphorus (PO_4-P), total phosphorus (TP), total Kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_3-N), nitrite-nitrogen (NO_2-N), nitrate-nitrogen (NO_3-N), and total suspended solids (TSS). NO_2-N, NO_3-N and TKN are summed to provide a measurement of total nitrogen (TN) in the water. Specific information on the location and water quality associated with these sampling sites can be found in TIAER's semi-annual water quality reports, such as Easterling et al. (1998) and Pearson and McFarland (1999).

There are two objectives to this report. The first is to use a statistical approach to develop nutrient export coefficients specific to the land uses within the Bosque River watershed using in-stream monitoring data for the period November 1, 1995 through March 30, 1998 for PO_4-P, TP and TN. This specific time period was chosen to maximize the number of sites available for use in loading calculations, while maintaining as long a data period as possible to account for temporal fluctuations in weather. Prior to November 1995, very little flow and water quality data were available for locations in the lower portion of the watershed (McFarland and Hauck, 1998a). After March 1998, several of the sampling sites in the upper portion of the watershed were removed due to a reprioritization of sampling needs (Pearson and McFarland, 1999). Two additional sites (NF020 on a tributary to the North Fork of the North Bosque River and NC060 on Neils Creek) were considered for this analysis but were removed from the analysis data set due to backwater impacts on level recordings during large storm events.

TP and TN were chosen as constituents for evaluation because phosphorus and nitrogen are the primary nutrients impacting the growth of algae in aquatic systems. PO_4-P was included as a separate phosphorus constituent, because PO_4-P represents most of the soluble phosphorus that is readily bioavailable for algal growth. In these freshwater systems, phosphorus is generally the limiting nutrient for the growth of algae (Gibson, 1997), and site specific studies indicate that this is the case for most locations within the Bosque River watershed (Dávalos-Lind and Lind, 1999; Matlock and Rodriguez, 1999). The second objective is to determine the relative nutrient contribution of the various point sources and nonpoint sources for the Bosque River watershed and for specific locations within the watershed. Loadings by source will be determined using the developed nutrient export coefficients and quantification of point source loadings for the WWTPs for the November 1, 1995 through March 30, 1998 time period.

Figure 4. Location of sampling sites used in nutrient export coefficient analysis for the Bosque River watershed.



METHODS

Land use information in conjunction with monitoring data were used to estimate nutrient export coefficients for nonpoint sources of PO_4-P, TP and TN by land-use category and to estimate the relative nutrient loadings by sector for point and nonpoint sources within the watershed using the following steps:

1. Determine the dominant land uses within the watershed and the percent of the drainage area above each monitoring site associated with these land uses.
2. Combine flow information with discrete measurements of nutrient concentrations taken during storm events and base flow to provide mass loadings for each sampling site.
3. Determine the nutrient export coefficients for urban land areas using mass loading information from the sole long-term, urban monitoring site (MB040).
4. Apply statistical models to determine optimal estimates of the nutrient export coefficients for the major agricultural land use categories within the watershed.
5. Compare estimated nutrient export coefficients for urban and agricultural land uses within the Bosque River watershed to values from other studies to evaluate the reasonableness of the developed export coefficients.
6. Determine mass loadings for the eight-permitted point source discharges (municipal WWTPs effluents) in the watershed using monitoring data and self-reporting effluent discharge information.
7. Develop an empirical source-contribution model using the nutrient export coefficients, land-use, and point source information to estimate loadings by source.
8. Validate the empirical source-contribution model by comparing measured nutrient loadings to predicted loadings for four sites along the North Bosque River (BO040, BO070, BO090 and BO100) not used in the development of the nutrient export coefficients (Step 4).

9. Determine the nutrient contribution by source for the entire watershed and various points within the watershed, and the uncertainty associated with these loading estimates.

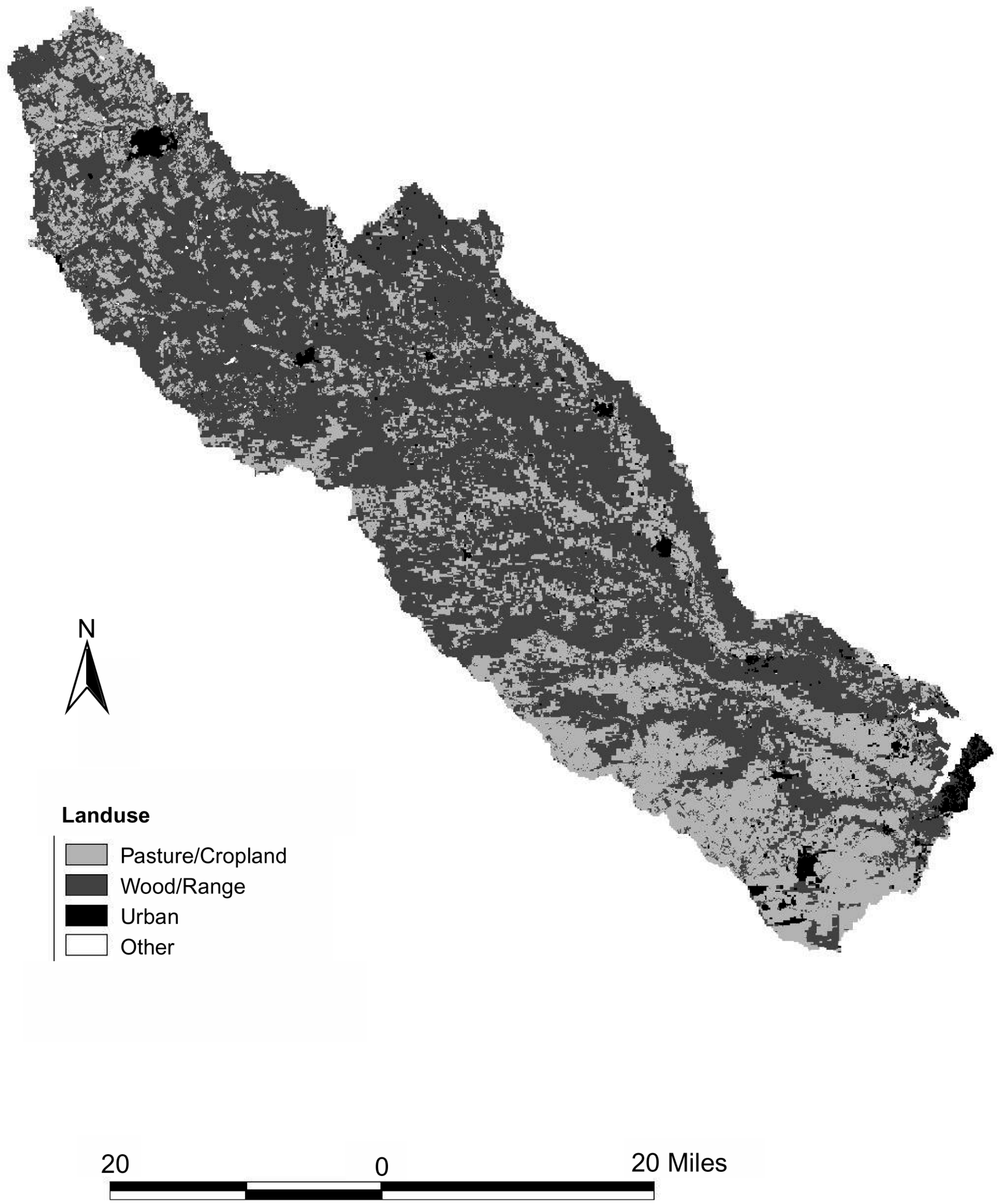
Step 1. Determine Land Uses Above Stream Sampling Sites

General land use descriptions were based on Landsat Thematic Mapper imagery classification provided by the USDA-NRCS Temple State Office as a Geographic Information System (GIS) data layer. The land use data were developed from an August 1992 overflight for Erath County and a June 1996 overflight for Bosque, Coryell, Erath, Hamilton, and McLennan counties. The June 1996 image was taken during a drought period, which caused difficulties in clearly distinguishing signatures between the different vegetation types. Cloud cover in the June 1996 image also caused problems in classifying the different land uses within the image. A 1992 land use classification was available from a previous TIAER project for the upper portion of the North Bosque River drainage from Hico, Texas and above. Extensive ground truthing implemented in January through April 1998 indicated very little change in land use from 1992 to 1998 for the area of the watershed within Erath County. The 1992 land use classification was updated to reflect the minor landuse changes from 1992 to 1998 and electronically inserted into the 1996 scene to represent the upper portion of the watershed within Erath County. For the lower portion of the Bosque watershed, digital orthophoto quadrangles from 1995 through 1996 and extensive ground truthing were used to verify and update the land use classification. The dominant land-use categories classified from the Landsat images were wood/range, pasture, cropland, urban and other (Figure 5).

The wood/range areas of the Bosque River watershed are part of the Cross Timbers vegetation region of Texas and are comprised primarily of scrub live oak (*Quercus virginiana*) and juniper (*Juniperus* spp.) in the woodland areas with tallgrass species such as little bluestem (*Schizachyruim scoparium*), indiangrass (*Sorghastrum nutans*) and switchgrass (*Panicum virgatum*) in the native rangeland areas (Schuster and Hatch, 1990). Pasture fields are predominately Coastal bermudagrass (*Cynodon* spp.).

A refinement was made to the cropland land use category based on the location of cropland areas within the watershed. Distinct differences in soil types and, thus, crops and management practices

Figure 5. General land use within the Bosque River watershed.



occur in different portions of the watershed. Most cropland areas in the upper portion of the watershed (Hico and above) are used to grow forage sorghum (*Sorghum* spp.) and winter wheat (*Triticum* spp.) as a double-crop system. In the lower portion of the watershed, particularly in the Hog Creek, Middle Bosque and South Bosque drainage areas, most cropland is used to grow row crops such as corn (*Zea mays* L.), grain sorghum (*Sorghum* spp.), soybeans (*Glycine* spp.) and cotton (*Gossypium hirsutum* L.). For evaluating nutrient export, cropland fields located in the Bosque River watershed above Hico were categorized as non-row crop and cropland fields located in the watershed below Hico were categorized as row crop.

Dairy locations and waste application fields could not be determined from the Landsat imagery. This information was obtained from dairy permits and dairy waste management plans on file with the State's environmental regulatory agency (the Texas Natural Resource Conservation Commission) and overlaid on the general land use data layer to represent a separate land use category (Figure 6). Waste application fields represent areas permitted for liquid and/or solid manure application and are primarily coastal bermudagrass fields. Solid manure is generally surface applied without incorporation on coastal bermudagrass fields, while a variety of irrigation systems are used to apply the liquid effluent. In the watershed, over 74 percent of the permitted dairy waste application fields are described as coastal bermudagrass fields (McFarland and Hauck, 1995), although crop rotations of sorghum and winter wheat are not uncommon. Operating dairies and the location of dairy waste application fields represent information as of January 1995.

The drainage areas above sampling sites (Table 2) were delineated from U.S. Geological Survey (USGS) 1:24,000 digital elevation models (DEMs) and USGS 7 ½-minute quadrangle maps digitized by the USDA-NRCS. The size of drainage areas for specific sites may vary somewhat from previous TIAER reports (less than 0.1 percent), particularly in the lower portion of the watershed, due to re-calculation of these drainage areas using an ARC/INFO rather than a GRASS (Geographic Resources Analysis Support System) based GIS platform. Land use composition within the drainage area above each sampling site was calculated by overlaying the drainage area and land use data layers within the GIS system. This was done for the individual sampling sites (Table 2) and for the entire Bosque River watershed and its major subwatersheds (Table 3).

Figure 6. Location of dairy waste application fields within the Bosque River watershed based on dairy permit information as of January 1995.

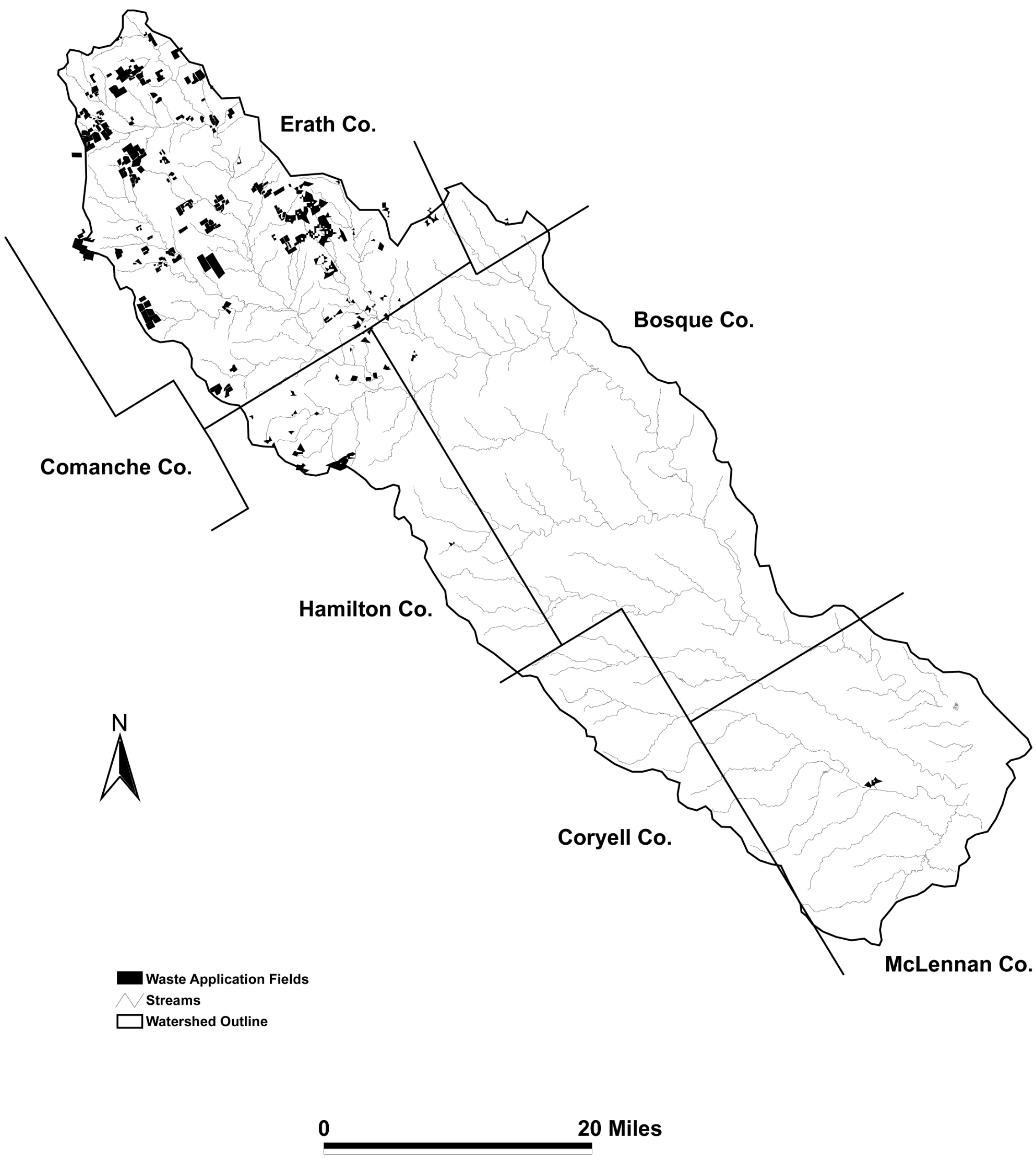


Table 2. Land uses above sampling sites and drainage area sizes for TIAER sampling sites in the Bosque River watershed used in nutrient export coefficient analyses.

Site	Wood/ Range (%)	Pasture (%)	Non-Row Crop (%)	Row Crop (%)	Dairy Waste Appl. (%)	Urban (%)	Other (%)	Drainage Area (acres)[†]
BO020	49.4	30.1	6.4	0.0	12.3	0.8	1.1	53,264
BO040	51.0	23.8	8.4	0.0	11.7	3.8	1.4	63,504
BO070	68.3	15.4	6.5	0.0	7.2	1.7	1.0	230,243
BO090	71.9	13.8	2.4	6.5	3.7	1.5	0.2	626,518
BO100	72.4	13.6	2.0	7.4	3.1	1.4	0.2	746,459
GB020	51.0	2.3	5.8	0.0	40.7	0.0	0.2	1,007
GC100	71.2	13.3	7.2	0.0	6.9	0.7	0.7	64,605
HC060	46.2	19.2	0.0	34.1	0.0	0.5	0.0	50,532
IC020	65.2	9.5	7.5	0.0	17.3	0.0	0.5	4,494
MB040	0.0	0.0	0.0	0.0	0.0	100.0	0.0	421
MB060	47.9	13.1	0.0	38.7	0.0	0.3	0.0	76,406
NF009	58.3	27.2	10.8	0.0	3.4	0.0	0.3	1,278
SC020	79.3	11.6	2.5	0.0	5.9	0.0	0.7	4,495
SF020	96.1	3.3	1.0	0.0	0.0	0.0	0.3	2,095
SF050	57.4	23.8	2.2	0.0	15.9	0.0	0.6	1,847
TC020	8.4	17.8	0.0	73.5	0.0	0.2	0.0	7,483
WC020	8.1	24.0	0.0	67.7	0.0	0.3	0.0	2,396

[†]Reported drainage areas determined using ARC/INFO vary somewhat from previously reported values determined using GRASS.

Table 3. Land use and drainage area size for major tributary drainages and total land area within the Bosque River watershed.

Drainage	Wood/ Range (%)	Dairy Waste Appl. (%)	Pasture (%)	Row Crop (%)	Non-Row Crop (%)	Urban (%)	Other (%)	Water (%)	Drainage Area (acres)[†]
North Bosque	72.19	2.97	13.64	6.69	2.68	1.43	0.21	0.20	781,403
Hog Creek	44.19	0.00	18.46	36.37	0.00	0.69	0.25	0.03	57,297
Middle Bosque	40.41	0.20	15.63	41.75	0.00	1.05	0.94	0.01	127,519
South Bosque	22.40	0.00	19.84	48.06	0.00	8.82	2.05	0.01	58,135
Other Minor Tribs.	35.43	0.00	6.69	12.59	0.00	21.93	0.97	0.01	30,842
Surface Area Lake Waco	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	7,270
Total	**62.80**	**2.21**	**14.35**	**15.18**	**1.97**	**2.34**	**0.42**	**0.73**	**1,062,466**

[†]Reported drainage areas determined using ARC/INFO vary somewhat from previously reported values determined using GRASS.

Step 2. Calculate Cumulative Nutrient Loadings for Each Site

Stormwater and routine grab samples were measured directly for TP, while TN values were derived as the sum of TKN, NO_2-N and NO_3-N. All nutrient analyses were performed using U. S. Environmental Protection Agency (EPA) approved methods (USEPA, 1983) and all samples were collected and analyzed under an EPA or TNRCC approved Quality Assurance Project Plan (e.g., TIAER, 1998).

Water level was monitored at each sampling site at five-minute intervals throughout the evaluation period. A stage-discharge relationship for most sites was determined from individual measurements of flow taken at a variety of water levels or stream stages. Manual flow measurements were made on an opportunistic basis representing a variety of streamflow conditions. Pairs of water level and flow data were then related to the cross-sectional area of the stream at each site and stream stage to develop site specific stage-discharge relationships. These relationships are updated if meaningful changes occur to a site's cross-sectional area. A semi-log relationship of average stream velocity to water level (log) was used to extrapolate flow for stream levels above which manual measurements could not be safely made. Because stream sites TC020 and WC020 are located at road culverts, hydraulic equations were applied to determine the stage-discharge relationship for these sites. At sites BO090 and BO100 flow data from corresponding USGS sites, 08095000 and 08095200 respectively, were obtained for use in this report. Flow at BO070 was calculated using the USGS stage-discharge relationship for station 08094800 in conjunction with level data measured by TIAER.

Flow data were then combined with the nutrient concentration data to calculate cumulative nutrient loadings at each site. This was done using a midpoint rectangular integration method to calculate loadings by dividing the flow hydrograph into intervals based on the collection date and time of each water quality sample (Stein, 1977). Stormwater samples were generally collected using a set sampling frequency depending on the size of the drainage area above the sampling site with more frequent sampling on the typically fast rising portion of the hydrograph and less frequent sampling on the typically slow receding portion of the hydrograph. A typical storm sampling sequence involved 1) an initial sample, 2) three samples at one-hour intervals, 3) four samples at two-hour intervals, and 4) all remaining samples for a storm event at six-hour intervals. Grab samples were collected bi-weekly during the study period and used to characterize base flow conditions. The history of nutrient loading at each site was summed for the evaluation period to obtain cumulative loadings over the study period. Cumulative loadings were prorated on an annual basis and area weighted for use in deriving nutrient export coefficients (Table 4).

In addition to the land use and WWTP loadings, the loadings of soluble phosphorus and nitrogen in precipitation to the surface area of Lake Waco were estimated based on analysis of precipitation data collected in the wet-dry atmospheric samplers located near Stephenville and Lake Waco. The Stephenville site was installed October 1996, while the Lake Waco site was installed in August 1997. No statistical differences were indicated in the constituent concentrations measured at these two sites, so data were combined to estimate precipitation loadings of nutrients to Lake Waco.

Table 4. Volume and nutrient loadings measured at TIAER sampling sites for November 1, 1995 through March 30, 1998 prorated to an annual basis.

Site	Flow (ft^3/yr)	Flow (ft^3/acre/yr)	PO_4-P (lbs/yr)	PO_4-P (lbs/acre/yr)	TP (lbs/yr)	TP (lbs/acre/yr)	TN (lbs/yr)	TN (lbs/acre/yr)
BO020	944,608,290	17,735	26,148	0.49	58,416	1.10	240,877	4.52
BO040	1,295,427,980	20,399	51,917	0.82	85,914	1.35	358,041	5.64
BO070	5,696,358,764	24,741	88,171	0.38	201,973	0.88	876,631	3.81
BO090	14,769,678,977	23,574	112,425	0.18	495,465	0.79	2,419,325	3.86
BO100	19,856,948,906	26,602	130,229	0.17	592,638	0.79	3,006,456	4.03
GB020	6,462,302	6,417	1,188	1.18	2,586	2.57	6,507	6.46
GC100	1,667,223,557	25,806	18,523	0.29	42,192	0.65	247,178	3.83
HC060	1,774,571,104	35,118	6,216	0.12	29,505	0.58	238,479	4.72
IC020	107,362,046	23,889	3,667	0.82	7,828	1.74	33,788	7.52
MB040	24,971,993	59,265	413	0.98	1,149	2.73	4,847	11.50
MB060	3,191,222,520	37,970	9,087	0.12	38,059	0.50	478,926	6.27
NF009	30,715,584	24,028	674	0.53	1,724	1.35	6,983	5.46
SC020	129,878,541	28,894	1,283	0.29	2,627	0.58	14,236	3.17
SF020	48,436,670	23,116	124	0.06	627	0.30	3,916	1.87
SF050	26,009,961	14,081	1,005	0.54	1,492	0.81	5,813	3.15
TC020	252,815,752	33,785	940	0.13	5,426	0.73	131,022	17.51
WC020	48,367,867	20,187	302	0.13	1,355	0.57	39,252	16.38

During the monitoring period, a total of 87.39 inches of rain was measured at the National Weather Service station at Waco Dam. The surface area of Lake Waco was estimated at 7,270 acres (TNRCC, 1996). During the monitoring period, 76 measurements were made of PO_4-P and 44 measurements of TP and TN from precipitation at the two locations. The median concentration values from these rainfall events were used to estimate loadings due to precipitation (Table 5). Compared to loadings at BO100 on the North Bosque River, precipitation loadings to Lake Waco contribute a very small percentage of the total loadings to Lake Waco (less than 1.5 percent of the loadings at BO100). Direct loadings of nitrogen and phosphorus from precipitation do occur, but because precipitation loading is a relatively minor contributor to the overall nutrient loadings to Lake Waco, it will be ignored in all further analyses in this report.

Table 5. Nutrient contribution to Lake Waco via precipitation for November 1, 1995 through March 30, 1998 assuming a reservoir surface area of 7,270 acres and 87.39 inches of rainfall prorated to an annual basis.

Nutrient Constituent	Median Concentration (mg/L)	Loading (lbs/yr)
PO_4-P	0.030	1,792
TP	0.075	4,480
TN	0.590	35,242

Step 3. Determine Nutrient Export Coefficients for Urban Land Areas

Most of the sampling sites represent predominately rural or agricultural land uses with urban areas comprising less than 3 percent of the total watershed area (Table 3). Site MB040, located in Stephenville, was the only sampling site representing 100 percent urban land (Table 2). The city of Waco is currently monitoring two urban runoff sites representing direct urban runoff into Lake Waco. The Waco urban runoff sites were installed in January and July 1997. The more limited data collection period for the two Waco sites precluded their use in this study. However, a general comparison of phosphorus and nitrogen at the Waco urban sites indicated that the values are comparable to data collected at site MB040. The nutrient export coefficients for urban land were, thus, calculated based on the area-weighted mass loadings for site MB040 (Table 4). Prorated to an annual basis the area-weighted nutrient loadings for MB040 for November 1, 1995 through March 30, 1998 produced urban export coefficients of 0.98 lbs PO_4-P/acre/year, 2.73 lbs TP/acre/year and 11.5 lbs TN/acre/year. While MB040 represents urban runoff from only one site within the watershed, the standard deviation associated with the urban nutrient export coefficients was set equal to the derived coefficient values for MB040 for use in Steps 7-9 to help evaluate the uncertainty associated with predicted urban loadings.

Step 4. Determine Nutrient Export Coefficients for Agricultural Land Uses

Typically export coefficients are determined by monitoring land uses, such as forest, row crops or urban, using field plots isolating individual land uses (Reckhow *et al.*, 1980). While monitoring single land-use watersheds may be ideal, most watersheds are comprised of a variety of land uses. The sampling network in the Bosque River watershed was designed to monitor nutrients and flow at stream sites with upstream drainage areas comprised of mixtures of land uses (McFarland and Hauck, 1998a).

To isolate the loading contribution from these mixed land-use drainage areas, multiple regression techniques were used to develop the nutrient export coefficients for the major agricultural land uses in the watershed based on procedures described by Hodge and Armstrong (1993). The dependent variable was the nutrient loading at each site (Table 4), and the independent variables were the fraction of the drainage area above each site represented by each land-use category (Table 2). The coefficients from the resulting multiple regression models define optimized export coefficients across all sites for each land use category for the time period evaluated. All multiple regression models were developed using a forced zero intercept, thus, giving a loading of zero if all land-use categories represented a zero fraction of the watershed. The procedures used follow closely those outlined in McFarland and Hauck (1998a) in their development of preliminary nutrient export coefficients for this watershed.

Of the 17 sites considered, 12 sites were used in estimating nutrient export coefficients for agricultural land uses. Sites BO040, BO070, BO090 and BO100 were reserved to validate the derived nutrient export coefficients, while site MB040 was used to calculate the urban nutrient export coefficients. Only the major land use categories of dairy waste application fields, pasture, non-row crop fields, row-crop fields and wood/range were considered as independent variables in the multiple regression models. All minor land uses represented as "other" in the land use classification represented relatively small percentages of the land cover and were assumed to be minor contributors (Table 2). Contributions for the "other" land-use category were considered part of the error term in the coefficient calculations.

Land uses were judiciously categorized to minimize multicolinearity effects in the multiple regression model procedures to obtain reasonable export coefficient estimates. Different groupings of sites were used to evaluate phosphorus and nitrogen export coefficients for the various land use categories due to observed loading differences at predominately cropland sites throughout the watershed. Specific methods used for estimating the phosphorus and nitrogen export coefficients are described below.

<u>Phosphorus Export Coefficients</u>: Three land-use category groupings were used to develop the phosphorus export coefficients for the rural land uses in the watershed: dairy waste application fields, pasture/cropland and range/wood. To minimize the impacts of multicolinearity, the pasture and cropland categories were joined into the combined land use category of pasture/cropland. Cropland for the phosphorus constituents included both non-row and row-crop fields as there appeared to be little difference in the phosphorus runoff at sites associated with these two land uses (Table 4).

In comparing the information in Tables 2 and 4, much larger phosphorus loadings are generally associated with sites containing substantial percentages of dairy waste application fields than with other sites. To avoid confounding phosphorus loadings from dairy waste application fields with other land uses, rural sampling sites without (or with minimal) dairy waste application fields in their drainage areas were grouped to estimate phosphorus export coefficients for the less impacted land uses of wood/range and pasture/cropland. The sites with no or minimal dairy waste application fields included HC060, MB060, SF020, TC020 and WC020. A multiple regression model using the fraction of pasture/cropland and wood/range as the independent variables and the phosphorus loading at these sites as the dependent variable was developed to estimate the phosphorus export coefficients for pasture/cropland and wood/range as follows:

$$\mathbf{P_i = \beta P_1 X_{i,1} + \beta P_2 X_{i,2} + \varepsilon_i} \qquad \textbf{(1)}$$

Where

i = the individual sites used in the regression model (for this specific model only data from sites HC060, MB060, SF020, TC020 and WC020 was used),

$\mathbf{P_i}$ = the annualized phosphorus loading at site i on a per acre basis of either PO_4-P or TP for the time period (lbs/acre/yr),

$\mathbf{\beta P_1}$ = the phosphorus export coefficient for pasture/cropland (lbs/acre/yr),

$\mathbf{X_{i,1}}$ = the fraction of the land area above site i represented by pasture/cropland,

$\mathbf{\beta P_2}$ = the phosphorus export coefficient for wood/range (lbs/acre/yr),

$X_{i,2}$ = the fraction of the land area above site i represented by wood/range,

ε_i = the random error associated with the difference between the measured and predicted loadings that is not explained by the model for site i.

The model was run separately for PO_4-P and TP. Prorated to an annual basis, the nutrient export coefficients derived are 0.14 lbs PO_4-P/acre/yr and 0.70 lbs TP/acre/yr for pasture/cropland and 0.07 lbs PO_4-P/acre/yr and 0.31 lbs TP/acre/yr for wood/range (Table 6).

Table 6. Phosphorus export coefficient parameter estimates on an annual basis for land-use variable versus nutrient loadings based on data from November 1, 1995 through March 30, 1998. 'na' indicates not applicable.

	PO_4-P (lbs/acre/yr)			TP (lbs/acre/yr)		
Land Use	**Parameter Estimate**	**p-value**	**n**	**Parameter Estimate**	**p-value**	**n**
Urban†	0.98±0.49	na	1	2.73±1.37	na	1
Dairy Waste Appl. Fields	3.08±0.34	0.0001	7	5.81±0.79	0.0003	7
Pasture/Cropland	0.14±0.01	0.0012	5	0.70±0.06	0.0013	5
Wood/Range	0.07±0.02	0.0184	5	0.31±0.07	0.0253	5

†The standard deviation for urban was estimated as one-half the value of the parameter estimate for use in further analyses.

A regression model evaluating the change in phosphorus loadings with changes in the fraction of land area represented by dairy waste application fields was determined using the seven sampling sites with drainage areas containing dairy waste application fields (BO020, GB020, GC100, IC020, NF009, SC020 and SF050) as shown below:

$$P_{i(adjusted)} = \beta P_3 X_{i,3} + \varepsilon_i \qquad (2)$$

Where

i = the individual sites used in the regression model (for this specific model, only data from sites with dairy waste application fields in their drainage areas were used),

$P_{i(adjusted)}$ = $P_i - (\beta P_1 X_{i,1} + \beta P_2 X_{1,2})$ from equation (1),

βP_3= the phosphorus export coefficient for dairy waste application fields (lbs/acre/yr),

$X_{i,3}$ = the fraction of the land area above site i represented by dairy waste application fields,

ε_i = the random error associated with the difference between the measured and predicted loadings that is not explained by the model for site i.

As indicated, equation (2) adjusts the loading P_i for the loading due to pasture/cropland and wood/range as calculated from equation (1). Prorated to an annual basis the export coefficients derived for dairy waste application fields are 3.08 lbs PO_4-P/acre/yr and 5.81 lbs TP/acre/yr (Table 6).

Nitrogen Export Coefficients: The land-use category groupings used to estimate the rural total-N export coefficients are the same as those for the phosphorus export coefficients (i.e., wood/range, pasture/cropland, and dairy waste application fields) except a refinement was made to the pasture/cropland grouping. Previously developed export coefficients for the upper North Bosque River watershed indicated the validity of grouping pasture and cropland together for all nutrients for that subwatershed of the Bosque River watershed (McFarland and Hauck, 1998b). The nutrient loading data (Table 4) and known differences in farming practices and soil types in the Bosque River watershed south of Hico, however, indicated the need to redefine the pasture/cropland grouping for the nitrogen export coefficients.

Much of the cropland in the upper portion of the watershed involves a double-cropping pattern of forage sorghum in the summer followed by a winter small grain, such as wheat or rye, as described in Step 1. Conditions, particularly soils, in the lower portion of the watershed are favorable for row crops such as corn and soybeans, which are typically not associated with a winter crop. Soil differences throughout the watershed contribute greatly to this change in cropping patterns as noted in USDA-NRCS soil surveys for Bosque, Coryell, Erath, Hamilton and McLennan counties. The nutrient loading data for sites in the lower portion of the watershed associated with row crop agriculture (TC020 and WC020, and to a lesser extent HC060 and MB060) showed high nitrogen loadings but fairly low phosphorus loadings in comparison to the other sites in the watershed (Table 4). These same high nitrogen loadings did not appear to be associated with the non-row crop agriculture associated with sites in the upper portion of the watershed. To account for this observed difference in nitrogen loadings between the row crop and non-row crop categories, row crop was evaluated as a separate land use category, although pasture and non-row crop areas were still combined for determining the export coefficients for TN.

As with the phosphorus coefficients, a two-step procedure was implemented to estimate the nitrogen export coefficients. This time the focus was on minimizing the confounding of the large nitrogen loading values associated with sites dominated by row-crop agriculture (Table 4). First, a multiple regression model was used to estimate the total-N export coefficients for the land-use categories of dairy waste application fields, pasture/non-row crop, and wood/range based on loading data using rural sampling sites only in the upper portion of the watershed above Hico. This approach was comparable to the procedures used in McFarland and Hauck (1998b) to estimate nutrient export coefficients for the upper North Bosque River watershed as follows:

$$\mathbf{N_i = \beta N_1 X_{i,1} + \beta N_2 X_{i,2} + \beta N_3 X_{i,3} + \varepsilon_i} \qquad \mathbf{(3)}$$

Where

i =	the individual sites used in the regression model (for this specific model only data from sites above Hico were used),
$\mathbf{N_i}$ =	the annualized nitrogen loading at site i on a per acre basis for the time period (lbs/acre/yr),
$\mathbf{\beta N_1}$=	the nitrogen export coefficient for dairy waste application fields (lbs/acre/yr),
$\mathbf{X_{i,1}}$ =	the fraction of the land area above site i represented by dairy waste application fields,
$\mathbf{\beta N_2}$=	the nitrogen export coefficient for pasture/non-row crop (lbs/acre/yr),
$\mathbf{X_{i,2}}$ =	the fraction of the land area above site i represented by pasture/ non-row crop,
$\mathbf{\beta N_3}$=	the nitrogen export coefficient for wood/range (lbs/acre/yr),
$\mathbf{X_{i,3}}$ =	the fraction of the land area above site i represented by wood/range,
$\mathbf{\varepsilon_i}$ =	the random error associated with the difference between the measured and predicted nitrogen loadings that is not explained by the model for site i.

Although statistically nonsignificant ($\alpha = 0.05$) coefficient values were estimated for pasture/non-row crop and wood/range using this procedure (Table 7), these coefficient values still represent the best optimized estimates from the current data set. Prorated on an annual basis the nitrogen export coefficients are 12.3 lbs TN/acre/yr for dairy waste application fields, 7.2 lbs TN/acre/yr for pasture/non-row crop fields, and 2.2 lbs TN/acre/yr for wood/range.

Table 7. Nitrogen export coefficient parameter estimates on an annual basis for land-use variable versus nutrient loadings based on data from November 1, 1995 through March 30, 1998. 'na' indicates not applicable.

Land Use	TN (lbs/acre/yr)		
	Parameter Estimate	p-value	n
Urban†	11.5 ± 5.8	na	1
Dairy Waste Appl. Fields	12.3 ± 4.2	0.0340	8
Pasture/Non-Row Crop	7.2 ± 4.0	0.1312	8
Wood/Range	2.2 ± 1.5	0.1974	8
Row Crop	19.0 ± 3.0	0.0078	4

†The standard deviation for urban was estimated as one-half the value of the parameter estimate for use in further analyses.

To estimate the TN export coefficient for row crops, a regression model was developed evaluating the change in TN loading with changes in the fraction of row crop in the drainage area above sites HC060, MB060, TC020 and WC020 as follows:

$$\mathbf{N_{i(adjusted)} = \beta N_4 X_{i,4} + \varepsilon_i} \qquad \mathbf{(4)}$$

Where

i = the individual sites used in the regression model (for this specific model only data from sites HC060, MB060, TC020 and WC020 were used),

$\mathbf{N_{i(adjusted)}}$ = $N_i - (\beta N_1 X_{i,1} + \beta N_2 X_{i,2} + \beta N_3 X_{i,3})$ from equation (3),

$\mathbf{\beta P_4}$ = the total nitrogen export coefficient for row-crop fields (lbs/acre/yr),

$\mathbf{X_{i,4}}$ = the fraction of the land area above site i represented by row-crop agriculture,

$\boldsymbol{\varepsilon_i}$ = the random error associated with the difference between the measured and predicted loadings that is not explained by the model for site i.

As indicated, equation (3) adjusts the loading of N_i for the loadings due to dairy waste application fields, pasture/cropland and wood/range as derived in equation (4). Prorated to an annual basis the nitrogen export coefficient for row crop is 19.0 lbs TN/acre/yr (Table 7).

Step 5. Compare Calculated Export Coefficients to Literature Values

To evaluate the reasonableness of the nutrient export coefficients derived in Step 4, the nutrient export coefficients for TP and TN were compared to values for similar land uses from other studies. Export coefficients for PO_4-P are generally not presented in nutrient export coefficient studies and, thus, could not be directly compared. Table 8 presents a general review of the range of published literature values for nutrient export coefficients focusing primarily on values for land uses most comparable to those in the Bosque River watershed. The coefficient values generated from the multiple regression models for TP and TN fit well within the range of literature values for the evaluated land use categories. The wide variability in literature values reflects site-specific variations in management and environmental conditions and emphases the advantage of using regional or site-specific export coefficients.

Table 8. Literature values for TP and TN export coefficients compared to calculated values for land uses in the Bosque River watershed.

Land Use	TP (lb/ac/yr)	TN (lb/ac/yr)	Source
Waste Appl. Fields	0.90 - 3.25	4.5 - 14.6	Loehr *et al.* (1989)
Waste Appl. Fields	1.68 - 13.78	7.4 - 111.8	Overcash *et al.* (1983)
Dairy Waste Appl. Fields	5.81	12.3	Bosque River Watershed
Pasture	0.06 - 0.67	3.6 - 15.7	Loehr *et al.* (1989)
Non-Row Crop	0.11 - 3.25	1.1 - 8.7	Reckhow *et al.* (1980)
Pasture/Non-Row Crop	0.70	7.2	Bosque River Watershed
Row Crop	0.02 - 20.83	2.8 - 89.2	Reckhow *et al.* (1980)
Row Crop	0.70	19.0	Bosque River Watershed
Forest	0.01 - 0.99	1.1 - 7.1	Loehr *et al.* (1989)
Idle Land	0.06 - 0.28	0.6 - 6.7	Loehr *et al.* (1989)
Native Pasture	0.02 - 2.08	0.2 - 10.3	Menzel *et al.* (1978)
Native Pasture	0.01 - 0.28	0.2 - 1.9	Timmons and Holt (1977)
Wood/Range	0.31	2.2	Bosque River Watershed
Urban	0.34 - 4.14	5.3 - 28.0	Loehr *et al.* (1989)
Urban	2.73	11.5	Bosque River Watershed

Step 6. Calculate Municipal WWTP Discharge Loadings

Nutrient loadings for the eight permitted WWTPs within the Bosque River watershed were estimated by integrating nutrient concentrations from monthly or bi-weekly grab samples of the effluent discharge with the average daily discharge data reported by each plant to the TNRCC. Since sampling at many of the WWTPs did not begin until January 1996, median values were used to represent the nutrient constituent concentrations for months during which samples were not collected. Cumulative loadings for November 1, 1995 through March 30, 1998 are presented in Table 9 prorated to an annual basis.

Table 9. Calculated wastewater treatment plant nutrient loadings for November 1, 1995 through March 30, 1998 prorated to an annual basis.

Site	Flow (ft^3/yr)	PO_4-P (lbs/yr)	TP (lbs/yr)	TN (lbs/yr)
Stephenville	86,356,413	11,523	14,381	37,542
Hico	3,929,640	658	751	2,872
Iredell	1,224,213	209	1,318	365
Meridian	9,252,524	1,468	1,763	10,214
Clifton	14,936,658	1,621	2,191	7,735
Valley Mills	4,569,215	710	793	4,820
McGregor	245,960	24	34	147
Crawford	34,785,358	2,210	3,330	21,693

Step 7. Develop an Empirical Source-Contribution Model

The export coefficient values, land-use classification, and point source data for the Bosque River were combined into an empirical source-contribution model. This model allows an estimation of the loading of nitrogen and phosphorus by source to the Bosque River watershed and other selected points for the time period of November 1, 1995 through March 30, 1998 as prorated on an annual basis. This simple empirical model can be expressed algebraically as follows:

$$\mathbf{L_{i,m}} = \sum_{j=1}^{7} (\mathbf{EC_{j,m}} \text{ x } \mathbf{SA_{i,j}}) + \sum_{k=1}^{8} \mathbf{PS_{i,k,m}} \qquad \textbf{(5)}$$

Where

m = the nutrient: m=1 for PO_4-P, m=2 for TP, and m=3 for TN,

i = a location with the Bosque River watershed, such as site BO040, for which land use information within the drainage of the site is defined,

$\mathbf{L_{i,m}}$ = annualized loading for nutrient m on a per acre basis to location i (lbs/acre/yr),

j = nonpoint sources: j = 1 for dairy waste application fields, j = 2 for pasture fields, j = 3 for non-row crop fields, j = 5 for row crop fields, j = 6 for wood/range, and j = 7 for urban,

$\mathbf{EC_{j,m}}$= land-use export coefficient (lbs/acre/yr) for source j and nutrient m,

$\mathbf{SA_{i,j}}$= land-use surface area within the drainage above location i associated with source j (acres),

k = the WWTPs: k = 1 for Stephenville, k = 2 for Hico, k = 3 for Iredell, k = 4 for Meridian, k = 5 for Clifton, k = 6 for Valley Mills, k = 7 for Crawford and k = 8 for McGregor, and

$\mathbf{PS_{i,k,m}}$= the annualized contribution at location i of nutrient m from the k municipal WWTP discharges above location i (lbs/yr).

Values for the variables in equation (5) can be obtained from Tables 2, 3, 6, 7 and 9. Percent contribution by source is calculated by dividing the total loading (L) to a given location by the calculated loading for each source.

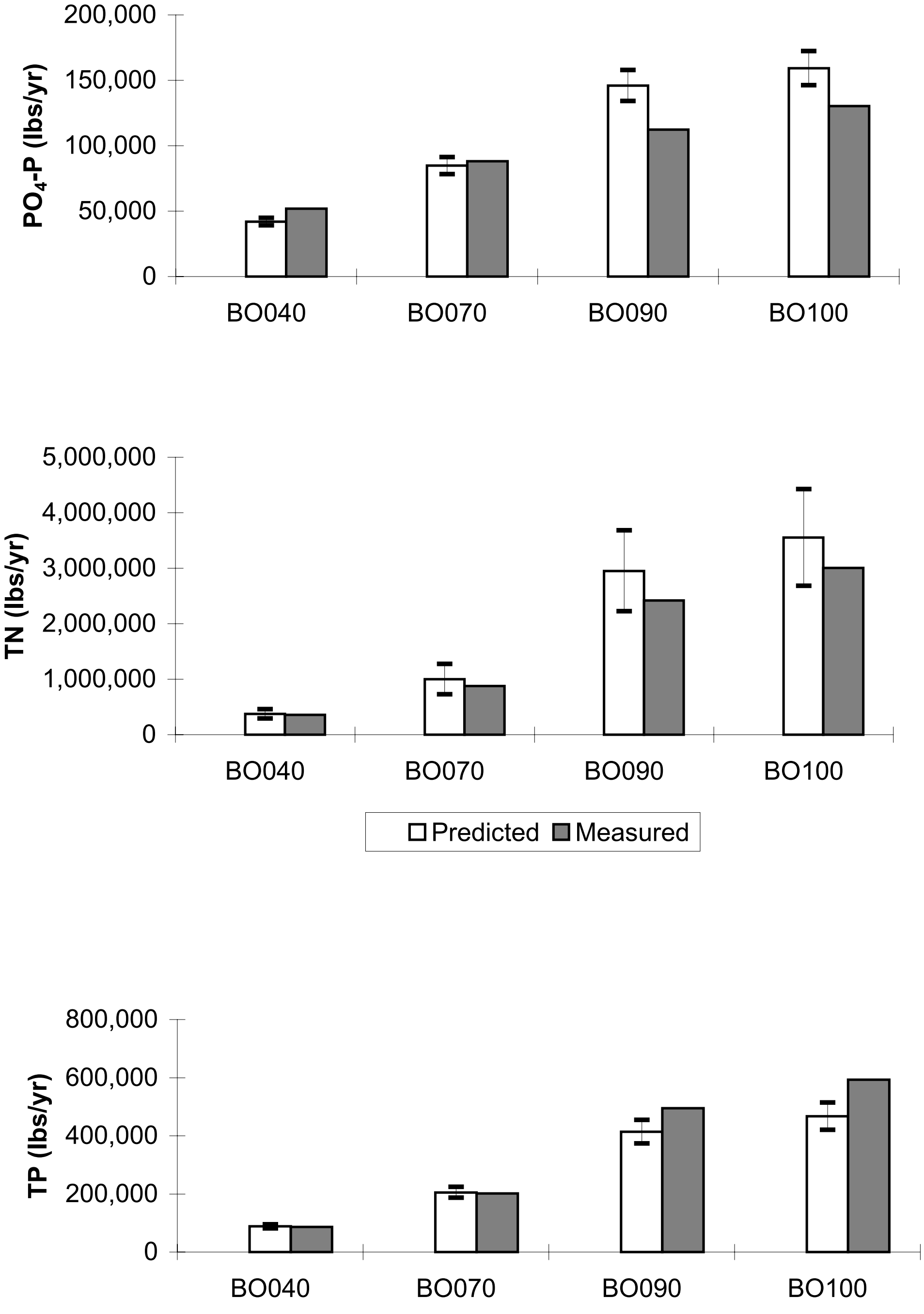
Because relatively large standard deviations were associated with the nutrient export coefficients for the agricultural land-use sectors using the regression methods (Tables 6 and 7), a Monte Carlo sampling technique (Law and Kelton, 1982) was integrated into the source-contribution model to take into account this variability. Monte Carlo simulation methods were used to predict loadings assuming a normal probability distribution as defined by the export coefficient and its standard deviation. As noted in Step 3, the standard deviation for each urban export coefficient was set equal to the derived coefficient value for this analysis. A total of 10,000 Monte Carol simulations were made. The results from the simulations were statistically analyzed to provide the average predicted loadings as well as a measure of the variance associated with the predicted loadings. The variability in WWTP loadings was not explored because these loadings were directly monitored, i.e., loadings from the WWTP were input as a constant value.

Step 8. Compare Estimated Nutrient Loadings with Monitored Loadings

Of the 17 automatic sampling sites in the watershed used for this analysis, four sites located along the North Bosque River (BO040, BO070, BO090 and BO100) were excluded from the export coefficient analysis, so they could be used to validate the coefficients developed. These four sites were selected as validation sites, because they represent the variety of point and nonpoint source nutrient loadings within the watershed. BO040, located on the North Bosque River below Stephenville, contains only a relatively small portion of urban land in its drainage basin (less than 4 percent) but is impacted by urban influences, particularly at base flow, due to its location about a quarter mile below the discharge of the Stephenville WWTP. Site BO070 is located on the North Bosque River at Hico, Texas, site BO090 is located near Clifton on the North Bosque River, and BO100 is located outside of Valley Mills along the North Bosque River (Figure 4). Site BO100 is also near the mouth of the North Bosque River drainage, thus, integrating the nutrient contributions for most of the North Bosque River subwatershed.

As validation of the estimated export coefficients, predicted loadings from the source-contribution model, as outlined in Step 7, were compared to measured loadings for North Bosque River sites BO040, BO070, BO090 and BO100, as presented in Table 4. A fairly good fit of predicted with measured data occurred with increasing differences generally occurring from upstream to downstream sites with values more closely predicted at sites BO040 and BO070 than at BO090 and BO100 (Figure 7). The larger errors at downstream sites were expected to some degree as drainage area and travel times increase. The source-contribution model reflects overall loadings into a watershed stream system and does not take into account in-stream losses and transformations beyond those accounted for by the use of in-stream data in deriving the nutrient export coefficients. In-stream transformations or losses may occur through such pathways as uptake of nitrogen and phosphorus by aquatic life, volatilization of NH_3-N to the atmosphere, sedimentation, and binding of PO_4-P to sediment particles.

Figure 7. Comparison of predicted with measured nutrient loadings on an annual basis for four sites along the North Bosque River for November 1, 1995 through March 30, 1998. Error bars represent plus and minus one standard deviation from the predicted mean.



While transformations and losses most likely explain the overestimation of PO_4-P and TN at sites BO090 and BO100 in the predicted values, the opposite is seen for TP. The predicted values for TP are notably underestimated at sites BO090 and BO100. This is an indication that the source-contribution model may not be accounting for all of the sources of TP contributing to the North Bosque River at sites BO090 and BO100 or that there may be some discrepancies in the measured data. A large amount of stream bank erosion was noted at sites BO090 and BO100 in association with large storm events that occurred in February 1997 and March 1998. This stream bank erosion may be an additional source of TP as increased in-stream TP concentrations were indicated for storm samples during these events in association with very high TSS concentrations. A fact confounding this explanation is that higher TN concentrations were also noted with these same samples, although predicted TN values on average overestimate rather than underestimate measured values at BO090 and BO100.

Another possible explanation for the poorer fit of the predicted versus measured data at BO090 and BO100 is the fact that the sampling program during the large February 1997 and March 1998 storm events had to be modified for safety reasons due to stream bank erosion at both sites. For at least part of each of these multi-day storm events, twice a day grab sampling from bridges near BO090 and BO100 was used rather than automatic sampling at set intervals.

Despite the discrepancies between predicted and measured phosphorus and nitrogen loadings apparent at sites BO090 and BO100, the overall agreement of predicted and measured nutrient loadings at the four North Bosque sites was very encouraging. The errors in predictions were within reasonable expectations from the application of an export coefficient approach. Even for direct measurements of in-stream loadings, an error of $\pm$25 percent in nutrient loadings is not uncommon (Loehr *et al.*, 1989). The differences between estimated and measured nutrient loadings are well within the range of what should reasonably be expected from an approach using export coefficients to estimate loadings. This verification exercise corroborates the validity of the nutrient export coefficients for the intended use of providing estimates of nutrient loadings by contributing sector for Bosque River watershed.

Step 9. Calculate Loadings and Percent Contribution by Subwatershed and Land-Use Sector

The source-contribution model, was applied to estimate loadings by subwatershed and source for the Bosque River watershed. The subwatersheds included the North Bosque River, Hog Creek, Middle Bosque River, South Bosque River, and a minor tributary group that included urban runoff from the city of Waco and smaller drainage areas near Lake Waco that were not included in other subwatershed areas (Figure 2).

As expected, the North Bosque River subwatershed was estimated to contribute the largest amount of nutrients to the Bosque River watershed compared to the other subwatersheds (Table 10). The North Bosque River watershed represents about 74 percent of the surface area of the entire Bosque River watershed and is estimated to contribute 78 percent of PO_4-P, 73 percent of TP and 57 percent of TN. A breakdown of the estimated percent contribution by land use for the entire Bosque River watershed is provided in Table 11. While comprising about 2 percent of the watershed area, dairy waste application fields were estimated to contribute on average 35 $\pm$ 4 percent of the PO_4-P, 21 $\pm$ 3 percent of the TP and 5 $\pm$ 2 percent of the TN within the Bosque River watershed during the period November 1, 1995 through March 30, 1998. Row crops were estimated to contribute the largest proportion of TN, averaging 49 $\pm$ 10 percent of the total loadings.

Table 10. Predicted annual loadings and percent of total loadings from major tributaries to the Bosque River watershed for November 1, 1995 through March 30, 1998.

	PO_4-P		TP		TN		Drainage Area
	Predicted (lbs/yr)	Percent of Total	Predicted (lbs/yr)	Percent of Total	Predicted (lbs/yr)	Percent of Total	Percent of Total
North Bosque River	163,605	78%	483,646	73%	3,710,493	57%	74%
Hog Creek	6,603	3%	30,744	5%	534,076	8%	5%
Middle Bosque River	16,076	8%	71,991	11%	1,291,180	20%	12%
South Bosque River	13,718	7%	48,827	7%	724,860	11%	6%
Other Minor Tributaries	8,369	4%	26,541	4%	195,195	3%	3%
Total Bosque River Watershed	208,371	100%	661,749	100%	6,455,805	100%	100%

Table 11. Estimated percent contribution of nutrients by source to the Bosque watershed for November 1, 1995 through March 30, 1998. 'na' indicates not applicable.

Source	PO_4-P (%)		TP (%)		TN (%)		Land Use (%)
	Mean	Std	Mean	Std	Mean	Std	
Dairy Waste Appl.	34.65	3.71	20.60	2.94	4.60	1.81	2.21
Row Crop	10.96	1.30	17.04	2.04	48.67	9.55	15.18
Non-Row Crop	1.42	0.18	2.21	0.28	2.42	1.37	1.97
Pasture	10.34	1.23	16.07	1.93	16.71	8.21	14.35
Wood/Range	22.35	4.44	30.45	5.61	21.68	11.68	62.80
WWTP	8.87	0.80	3.56	0.35	1.39	0.28	na
Urban	11.42	5.12	10.06	4.59	4.55	2.34	2.34

For the North Bosque River drainage area, the largest PO_4-P loadings were associated with dairy waste application with wood/range representing the next largest loading source (Table 12). For TP, these two land uses were reversed with wood/range being the largest contributing source followed by dairy waste application fields. Row-crop agriculture and wood/range were the largest contributing sources of TN to the North Bosque River drainage, both contributing about 31 percent of the total estimated loading. Pasture was the next largest contributor of TN representing almost 21 percent of the total estimated. A breakdown of the estimated loadings by source for the major subwatersheds within the Bosque River watershed is provided in Appendix A.

Table 12. Estimated percent contribution of nutrients by source to the North Bosque River watershed for November 1, 1995 through March 30, 1998. 'na' indicates not applicable.

Source	PO_4-P (%)		TP (%)		TN (%)		Land Use (%)
	Mean	Std	Mean	Std	Mean	Std	
Dairy Waste Appl.	43.71	3.99	28.02	3.81	8.12	3.47	2.97
Row Crop	4.99	0.59	8.37	1.09	31.23	8.99	7.35
Non-Row Crop	1.37	0.17	2.30	0.31	3.27	1.96	2.02
Pasture	9.23	1.07	15.48	1.94	20.63	10.31	13.64
Wood/Range	24.12	4.62	35.35	6.03	31.22	15.65	72.19
WWTP	9.95	0.84	4.20	0.44	1.86	0.52	na
Urban	6.64	3.11	6.29	2.98	3.68	2.05	1.43

Because the TMDL effort is specifically directed at segments 1226 and 1255 on the North Bosque River, the percent contribution by land-use sector was estimated for the drainage areas above eight points along the North Bosque River. These eight points correspond to sampling sites BO020, BO040, BO060, BO070, BO080, BO085, BO090, and BO100 (Figure 8). Sites BO040, BO070, BO090 and BO100 were used in Step 8 for model validation. Site BO020, located above Stephenville, was used in deriving the nutrient export coefficients in Step 7. Sites BO060, located between Stephenville and Hico, BO080, located near Iredell, and BO085, located near Meridian, do not have automatic samplers and are used only as grab sampling sites for water quality analysis in the monitoring program (Pearson and McFarland, 1999).

Of interest is the spatial distribution of loadings in the North Bosque River drainage (Figure 9). A disproportionately high percentage of the phosphorus loadings, particularly PO_4-P, occur in the upper portion of the North Bosque River drainage, while nitrogen loadings appear to be more evenly distributed throughout the drainage. The land use for these sites indicates that most of the dairy waste application fields, which are associated with relatively high phosphorus and nitrogen loadings, are found in the upper portion of the watershed, while row-crop areas, which are associated with relatively high nitrogen loadings, are located in the lower portion of the watershed (Table 13). Detailed results of estimated loadings by source presented in Appendix B confirm this distribution of loadings.

Table 13. Land uses within the drainage areas above TIAER sampling sites along the North Bosque River.

Site	Wood/ Range (%)	Pasture (%)	Non-Row Cropland (%)	Row Crop (%)	Dairy Waste Appl. Fields (%)	Urban (%)	Other (%)	Drainage Area (Acres)[†]
BO020	49.4	30.1	6.4	0.0	12.3	0.8	1.0	53,264
BO040	51.1	23.8	8.4	0.0	11.7	3.8	1.2	63,504
BO060	60.5	19.1	7.3	0.0	9.2	2.8	1.1	120,936
BO070	68.2	15.4	6.5	0.0	7.2	1.7	1.0	230,243
BO080	69.0	16.0	4.1	2.5	6.4	1.7	0.3	361,014
BO085	71.3	14.5	3.2	4.1	5.0	1.6	0.3	468,115
BO090	71.9	13.8	2.4	6.5	3.7	1.5	0.2	626,518
BO100	72.4	13.6	2.0	7.4	3.1	1.4	0.1	746,469

[†]Reported drainage areas determined using ARC/INFO vary somewhat from previously reported values determined using GRASS.

Figure 8. Location of TIAER sampling sites along the North Bosque River.

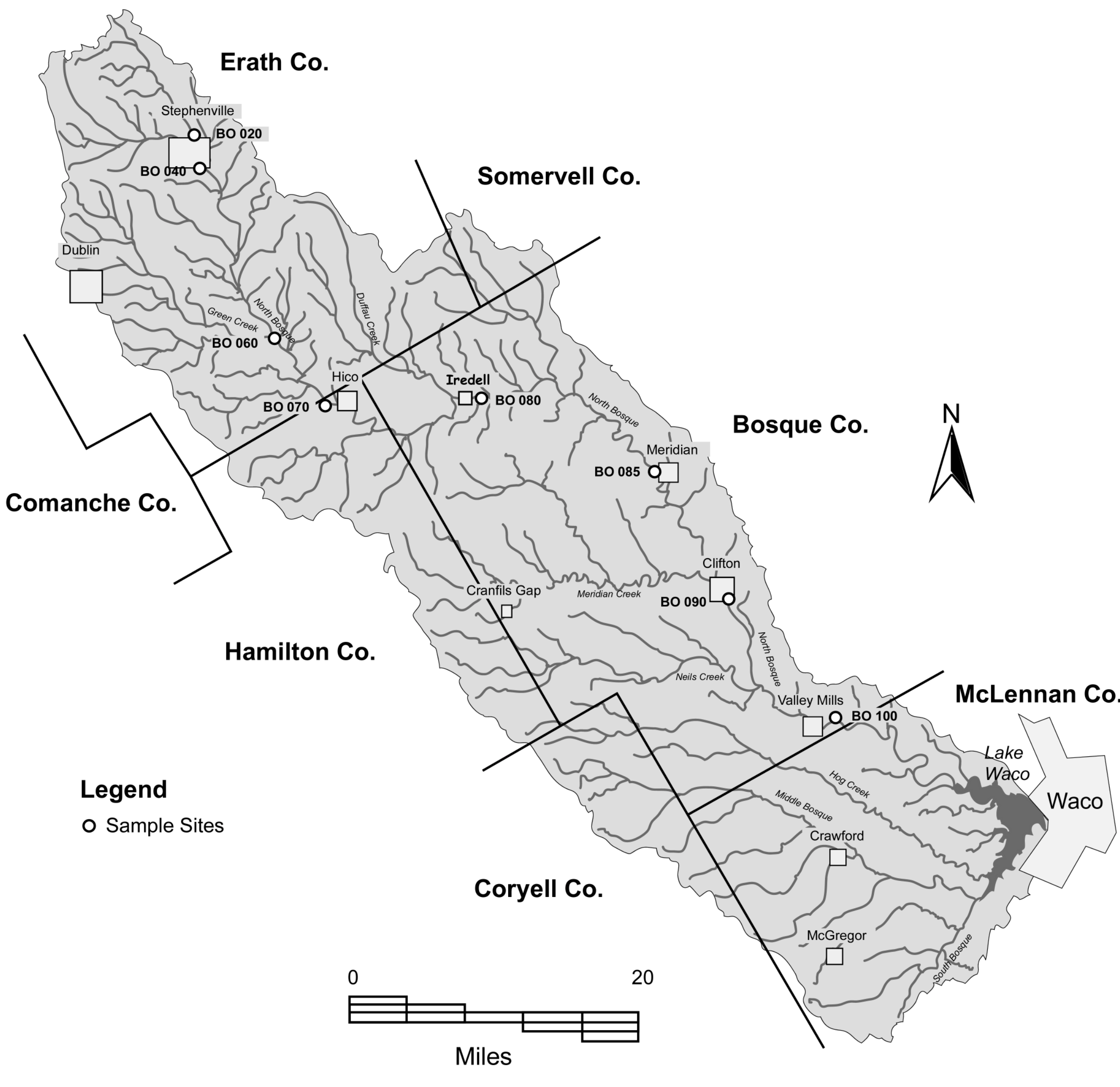
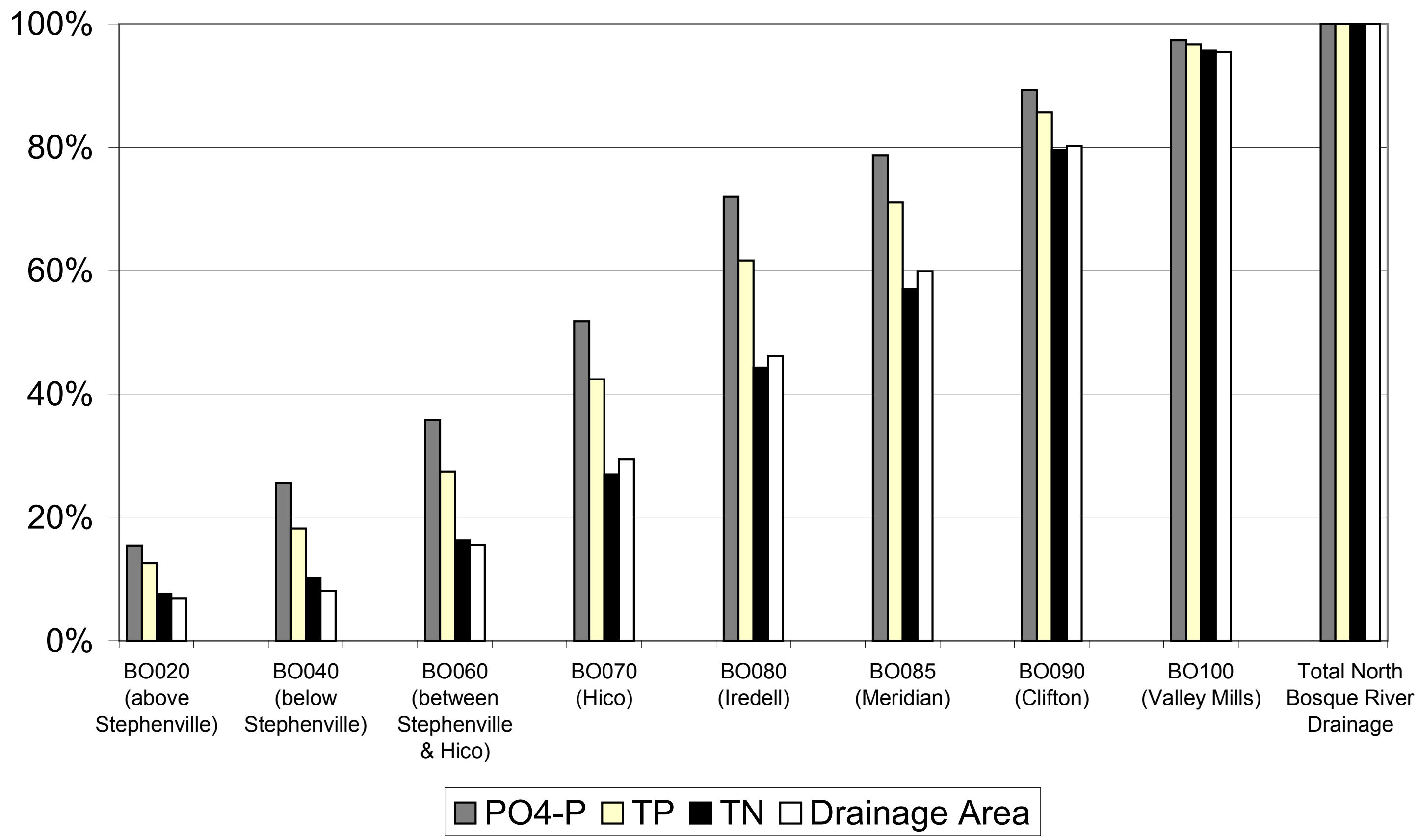


Figure 9. Percent of predicted nutrient loadings compared with percent of total drainage area represented for selected sites along the North Bosque River.



DISCUSSION AND CONCLUSIONS

The agricultural export coefficients, while based on an extremely large database from a monitoring perspective, represent a relatively small database (12 sites) from a statistical perspective. Ideally, 30 or more sites would be used in such an analysis to give adequate power to the regression analysis approach of estimating nutrient export coefficients. The relatively large standard deviations associated with the nutrient export coefficients partially reflect the size of the data set from which these coefficients were derived as well as the inherent variability in environmental characteristics. This variability arises from the spatial distribution in slope, soils, and management practices associated with each land use. Additional sites, representing a broader range of each land use category, both urban and agricultural, might help refine these nutrient export coefficients. The Monte Carlo analysis used in this study helps take into account a large portion of the variability associated with the individual export coefficients for the various land uses without the expense and time of collecting additional data.

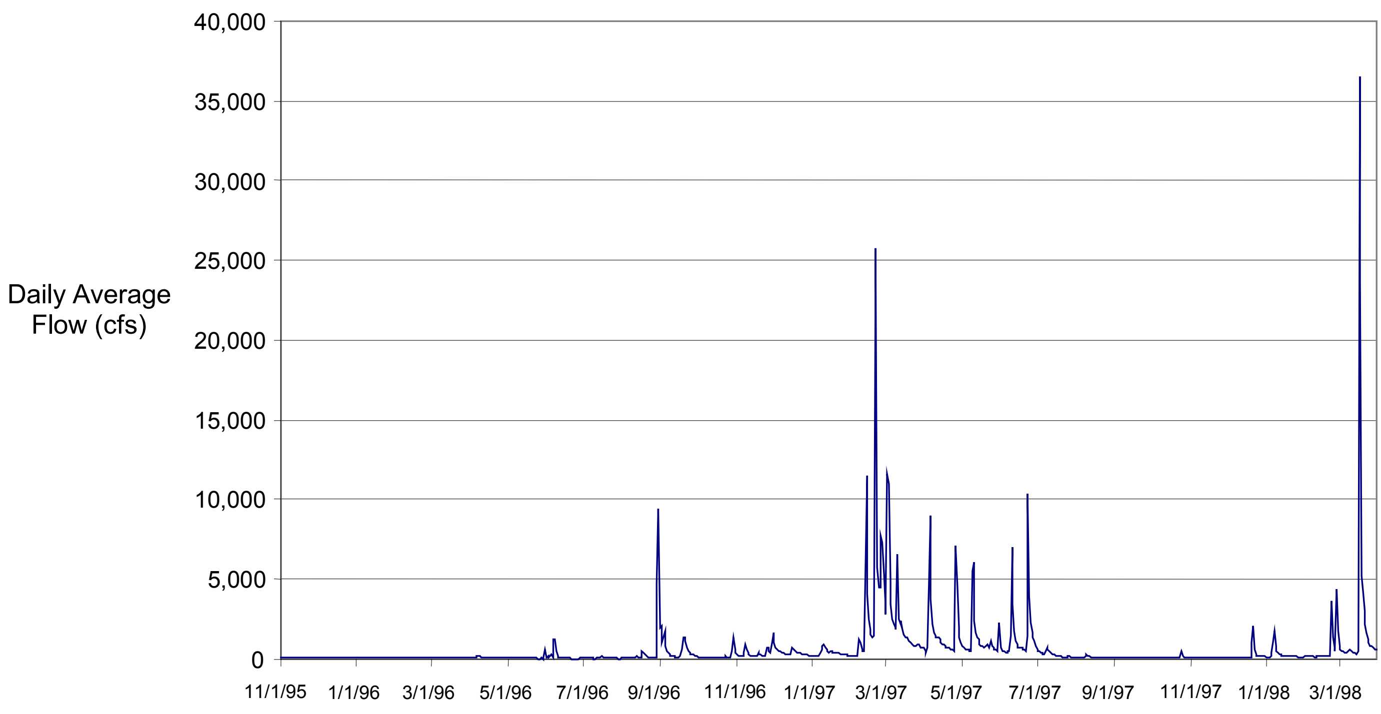
The multiple regression approach for determining nutrient export coefficients maximizes the use of streamflow and water quality data from steam sites with mixed land-use drainage areas within a monitoring network without the need for isolating individual land uses. Further, the multiple regression method provides export coefficients representing the average of conditions and practices (e.g., soils, planting and harvest dates, fertilization timing and amounts, slopes, tillage practices, and proximity to streams) of each land use across the Bosque River watershed, as opposed to export coefficients determined for the more limited practices and conditions of small, single land-use drainage areas. Whether determined by regression techniques from in-stream monitoring sites, as in this study, or from monitoring of individual land uses, the export coefficients are indicative of the climatic conditions under which the monitoring data were collected. The longer the duration of the monitoring data set, the more likely the export coefficients include a range of weather conditions (e.g., high and low rainfall periods), typifying average nutrient contributions, and do not include potentially undesirable biases from over representation of meteorological extremes.

Export coefficients are highly dependent on the environmental conditions from which they are based and extrapolation to other time periods or regions can be problematic. It should be emphasized that large storm events carry the majority of the nutrient loadings within the Bosque River watershed. For the monitoring period November 1, 1995 and March 30, 1998 about 50 percent of the flow at BO100, North Bosque River near Valley Mills, occurred in the months of February 1997 and March 1998 (Figure 10). In comparison to long-term monthly flow data for the USGS gauging station near BO100, February 1997 represents the highest month of flow on record and March 1998 represents the third highest month of flow on record. During the study period, the flow at BO100 averaged 630 cfs more than double the long-term average of 283 cfs for 1960 through 1995. These above average hydrologic conditions should be considered in using the calculated export coefficient values beyond the time period evaluated and in evaluating the relative nutrient contribution by sector. A reasonable expectation is that point source loadings associated with WWTPs will increase in relative important as contributors of nutrients with decreasing rainfall and stream flow. This underscores the importance of understanding the climatic and hydrologic conditions under which export coefficients are determined before using them in watershed planning efforts. The derived nutrient export coefficients and, thus, the source-contribution model results presented in this study are specific to the time period November 1, 1995 through March 30, 1998 and care should be taken in extrapolating these results to other timeframes or watersheds.

The calculated agricultural and urban nutrient export coefficients do provide a good indication of the nutrient contribution from land uses within the upper North Bosque River watershed for PO_4-P, TP and TN for November 1, 1995 through March 30, 1998. Export coefficient values from this study were within the range of values for similar land uses reported in the literature for other studies. Predicted loadings of PO_4-P, TP and TN using export coefficient values in the source-contribution model also compared favorably with measured loadings at North Bosque River sites BO040, BO070, BO090 and BO100 used for model validation.

The largest relative contributions of PO_4-P, TP and TN within the Bosque River watershed were associated with the North Bosque River subwatershed, which is expected as the North Bosque River drainage represents about 74 percent of the total Bosque River watershed. For the study period, over 70 percent of the PO_4-P and TP and over 50 percent of the TN loadings were associated with the North Bosque River subwatershed. A significant proportion of the TN loadings were also associated with subwatersheds in the southern portion of the watershed, i.e., Hog Creek, Middle Bosque River and South Bosque River. The largest contributing source of PO_4-P and TP to the Lake Waco/Bosque River drainage were dairy waste application fields and wood/rangeland, while the largest contributing source of TN was row-crop fields. Most dairy waste application fields in the watershed are found in the upper portion of the North Bosque River drainage area, while most row-crop fields are found in the southern portion of the watershed within the Hog Creek, Middle Bosque and South Bosque River drainage areas.

Figure 10. Average daily flow at site BO100 on the North Bosque River near Valley Mills for November 1, 1995 through March 30, 1998.



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APPENDIX A: NUTRIENT CONTRIBUTION BY SOURCE FOR MAJOR SUBWATERSHEDS WITHIN THE BOSQUE RIVER WATERSHED

Table A-1. Estimated percent contribution of nutrients by source within the North Bosque River drainage area for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

	PO_4-P (%)		TP (%)		TN (%)		Land Use (%)
Source	**Mean**	**Std**	**Mean**	**Std**	**Mean**	**Std**	
Dairy Waste Appl.	43.71	3.99	28.02	3.81	8.12	3.47	2.97
Row Crop	4.99	0.59	8.37	1.09	31.23	8.99	7.35
Non-Row Crop	1.37	0.17	2.30	0.31	3.27	1.96	2.02
Pasture	9.23	1.07	15.48	1.94	20.63	10.31	13.64
Wood/Range	24.12	4.62	35.35	6.03	31.22	15.65	72.19
WWTP	9.95	0.84	4.20	0.44	1.86	0.52	na
Urban	6.64	3.11	6.29	2.98	3.68	2.05	1.43

Table A-2. Estimated percent contribution of nutrients by source within the Hog Creek drainage area for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

	PO_4-P (%)		TP (%)		TN (%)		Land Use (%)
Source	**Mean**	**Std**	**Mean**	**Std**	**Mean**	**Std**	
Dairy Waste Appl.	0	0	0	0	0	0	0
Row Crop	44.71	3.94	47.42	3.82	74.75	8.28	36.37
Non-Row Crop	na	na	na	na	na	na	na
Pasture	22.68	2.39	24.05	2.36	14.00	6.90	18.46
Wood/Range	26.78	4.92	25.02	4.80	10.37	6.18	44.19
WWTP	0	0	0	0	0	0	na
Urban	5.83	2.74	3.51	1.68	0.87	0.45	0.69

Table A-3. Estimated percent contribution of nutrients by source within the Middle Bosque River drainage area for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

	PO_4-P (%)		TP (%)		TN (%)		Land Use (%)
Source	**Mean**	**Std**	**Mean**	**Std**	**Mean**	**Std**	
Dairy Waste Appl.	4.91	0.65	2.07	0.32	0.25	0.09	0.20
Row Crop	46.89	3.91	51.70	3.80	78.75	7.07	41.75
Non-Row Crop	na	na	na	na	na	na	na
Pasture	17.55	1.88	19.35	1.92	11.00	5.56	15.63
Wood/Range	22.44	4.38	21.78	4.37	8.77	5.29	40.41
WWTP	0.15	0.01	0.05	0	0.01	0	na
Urban	8.06	3.71	5.05	2.39	1.22	0.62	1.05

Table A-4. Estimated percent contribution of nutrients by source within the South Bosque River drainage area for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

Source	PO_4-P (%) Mean	PO_4-P (%) Std	TP (%) Mean	TP (%) Std	TN (%) Mean	TN (%) Std	Land Use (%)
Dairy Waste Appl.	0	0	0	0	0	0	0
Row Crop	29.70	5.93	40.69	6.27	73.51	6.50	48.06
Non-Row Crop	na	na	na	na	na	na	na
Pasture	12.25	2.55	16.79	2.79	11.30	5.66	19.84
Wood/Range	6.83	2.02	8.24	2.24	3.98	2.50	22.20
WWTP	16.68	3.23	6.97	1.06	3.05	0.45	na
Urban	34.54	12.46	27.31	10.57	8.15	3.88	8.82

Table A-5. Estimated percent contribution of nutrients by source within the minor tributaries within the Bosque River Watershed near Lake Waco area for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

Source	PO_4-P (%) Mean	PO_4-P (%) Std	TP (%) Mean	TP (%) Std	TN (%) Mean	TN (%) Std	Land Use (%)
Dairy Waste Appl.	0	0	0	0	0	0	0
Row Crop	8.21	5.43	11.90	5.83	39.70	10.37	12.59
Non-Row Crop	na	na	na	na	na	na	na
Pasture	4.36	2.90	6.31	3.12	7.87	4.44	6.69
Wood/Range	13.31	9.00	16.95	8.74	14.44	8.73	41.27
WWTP	0	0	0	0	0	0	na
Urban	74.13	16.85	64.84	16.89	37.99	13.88	21.93

APPENDIX B: NUTRIENT CONTIBUTION BY SOURCE FOR SELECTED SITES ALONG THE NORTH BOSQUE RIVER

Table B-1. Estimated percent contribution of nutrients by source for the drainage area above site BO100 on the North Bosque River for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

Source	PO_4-P (%)		TP (%)		TN (%)		Land Use (%)
	Mean	Std	Mean	Std	Mean	Std	
Dairy Waste Appl.	44.88	4.01	28.97	3.89	8.48	3.60	3.1
Row Crop	4.89	0.58	8.27	1.07	31.15	8.96	7.4
Non-Row Crop	1.35	0.16	2.27	0.30	3.26	1.96	2.0
Pasture	9.02	1.04	15.23	1.90	20.50	10.27	13.6
Wood/Range	23.72	4.57	35.01	6.00	31.22	15.65	72.4
WWTP	9.77	0.82	4.17	0.44	1.79	0.50	na
Urban	6.39	3.00	6.10	2.90	3.60	2.01	1.4

Table B-2. Estimated percent contribution of nutrients by source for the drainage area above site BO090 on the North Bosque River for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

Source	PO_4-P (%)		TP (%)		TN (%)		Land Use (%)
	Mean	Std	Mean	Std	Mean	Std	
Dairy Waste Appl.	48.95	4.04	32.68	4.16	10.20	4.30	3.7
Row Crop	3.95	0.47	6.89	0.89	27.77	8.20	6.5
Non-Row Crop	1.47	0.18	2.56	0.33	3.92	2.35	2.4
Pasture	8.42	0.97	14.70	1.81	21.10	10.53	13.8
Wood/Range	21.61	4.28	32.99	5.84	31.35	15.74	71.9
WWTP	9.54	0.79	4.17	0.43	1.88	0.53	na
Urban	6.08	2.86	6.00	2.85	3.78	2.12	1.5

Table B-3. Estimated percent contribution of nutrients by source for the drainage area above site BO085 on the North Bosque River for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

Source	PO_4-P (%)		TP (%)		TN (%)		Land Use (%)
	Mean	Std	Mean	Std	Mean	Std	
Dairy Waste Appl.	55.34	3.96	39.25	4.51	14.22	5.98	5.0
Row Crop	2.12	0.25	3.93	0.50	18.51	6.02	4.1
Non-Row Crop	1.65	0.20	3.07	0.39	5.44	3.29	3.2
Pasture	7.47	0.86	13.87	1.68	23.02	11.44	14.5
Wood/Range	18.19	3.77	29.54	5.52	32.41	16.26	71.3
WWTP	9.66	0.79	4.51	0.45	2.12	0.65	na
Urban	5.57	2.63	5.84	2.77	4.28	2.45	1.6

Table B-4. Estimated percent contribution of nutrients by source for the drainage area above site BO080 on the North Bosque River for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

Source	PO_4-P (%) Mean	PO_4-P (%) Std	TP (%) Mean	TP (%) Std	TN (%) Mean	TN (%) Std	Land Use (%)
Dairy Waste Appl.	59.89	3.73	44.71	4.60	18.10	7.45	6.4
Row Crop	1.09	0.13	2.13	0.27	11.27	3.85	2.5
Non-Row Crop	1.78	0.21	3.49	0.44	6.92	4.16	4.1
Pasture	6.95	0.80	13.59	1.61	25.13	12.25	16.0
Wood/Range	14.88	3.00	25.45	5.04	31.40	16.05	69.0
WWTP	10.41	0.84	5.12	0.49	2.66	0.83	na
Urban	5.00	2.37	5.51	2.62	4.53	2.60	1.7

Table B-5. Estimated percent contribution of nutrients by source for the drainage area above site BO070 on the North Bosque River for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

Source	PO_4-P (%) Mean	PO_4-P (%) Std	TP (%) Mean	TP (%) Std	TN (%) Mean	TN (%) Std	Land Use (%)
Dairy Waste Appl.	60.37	3.54	47.17	4.56	21.67	9.00	7.2
Row Crop	na	na	na	na	na	na	0.0
Non-Row Crop	2.49	0.29	5.09	0.62	11.35	6.70	6.5
Pasture	5.91	0.67	12.10	1.43	25.46	12.66	15.4
Wood/Range	13.03	2.86	23.35	4.75	32.53	16.65	68.3
WWTP	13.67	1.07	7.07	0.66	4.09	1.40	na
Urban	4.53	2.16	5.22	2.49	4.89	2.89	1.7

Table B-6. Estimated percent contribution of nutrients by source for the drainage area above site BO060 on the North Bosque River for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

Source	PO_4-P (%) Mean	PO_4-P (%) Std	TP (%) Mean	TP (%) Std	TN (%) Mean	TN (%) Std	Land Use (%)
Dairy Waste Appl.	58.12	3.89	48.47	4.34	23.32	8.86	9.2
Row Crop	na	na	na	na	na	na	0.0
Non-Row Crop	2.13	0.24	4.65	0.55	10.89	6.17	7.3
Pasture	5.57	0.62	12.18	1.39	26.81	12.57	19.1
Wood/Range	8.80	2.01	16.87	3.70	25.56	13.93	60.5
WWTP	19.77	1.47	10.92	0.96	6.63	1.93	na
Urban	5.62	2.65	6.91	3.24	6.78	3.73	2.8

Table B-7. Estimated percent contribution of nutrients by source for the drainage area above site BO040 on the North Bosque River for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

Source	PO_4-P (%) Mean	PO_4-P (%) Std	TP (%) Mean	TP (%) Std	TN (%) Mean	TN (%) Std	Land Use (%)
Dairy Waste Appl.	54.44	3.22	48.78	4.13	24.80	8.76	11.7
Row Crop	na	na	na	na	na	na	0.0
Non-Row Crop	1.80	0.20	4.22	0.49	10.49	5.78	8.4
Pasture	5.10	0.55	11.98	1.32	27.87	12.52	23.8
Wood/Range	5.46	1.28	11.27	2.61	18.68	10.80	51.0
WWTP	27.65	1.89	16.42	1.36	10.55	2.69	na
Urban	5.56	2.61	7.34	3.42	7.61	4.01	3.8

Table B-8. Estimated percent contribution of nutrients by source for the drainage area above site BO020 on the North Bosque River for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

Source	PO_4-P (%) Mean	PO_4-P (%) Std	TP (%) Mean	TP (%) Std	TN (%) Mean	TN (%) Std	Land Use (%)
Dairy Waste Appl.	80.01	2.47	62.45	4.01	29.79	11.78	12.3
Row Crop	na	na	na	na	na	na	0.0
Non-Row Crop	1.91	0.24	3.91	0.49	9.20	5.67	6.4
Pasture	9.02	1.11	18.45	2.14	38.67	16.08	30.1
Wood/Range	7.37	1.76	13.24	3.07	20.44	12.31	49.4
WWTP	0.00	0.00	0.00	0.00	0.00	0.00	na
Urban	1.69	0.83	1.95	0.96	1.91	1.16	0.8