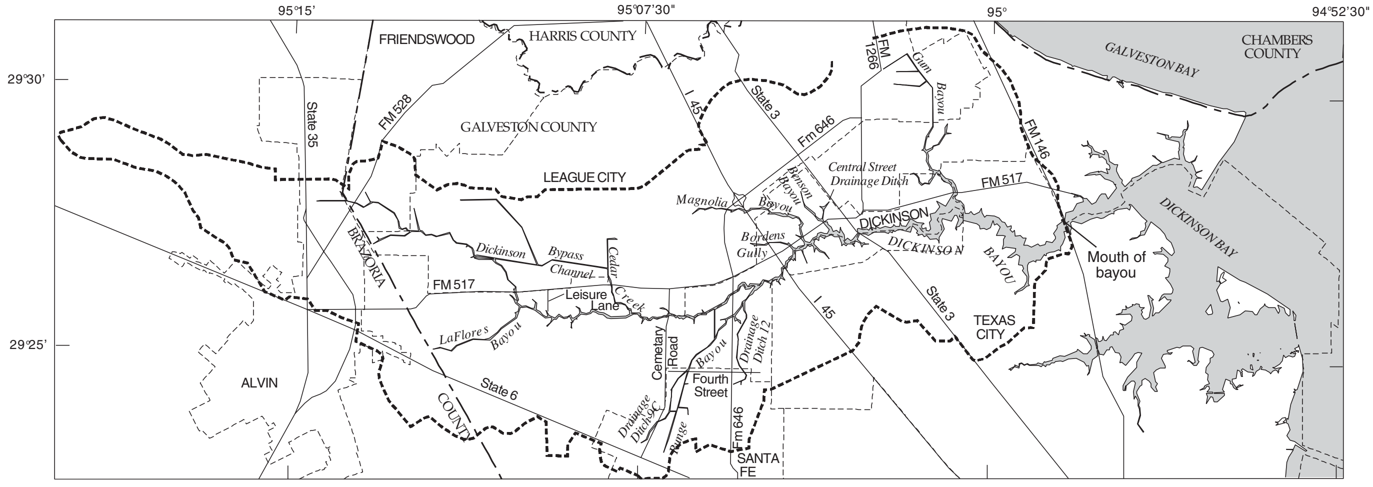
In cooperation with the Houston-Galveston Area Council
and the Texas Natural Resource Conservation Commission
under the authorization of the Texas Clean Rivers Act

Nutrient Loading and Selected Water-Quality and Biological Characteristics of Dickinson Bayou Near Houston, Texas, 1995–97

Water-Resources Investigations Report 98–4012



U.S. Department of the Interior
U.S. Geological Survey

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By Jeffery W. East, Edna M. Paul, and Stephen D. Porter

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In cooperation with the Houston-Galveston Area Council
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1998

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VERTICAL DATUM AND ABBREVIATIONS

Sea Level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviations:

cm, centimeter
cols./100 mL, colonies per 100 milliliters
ft, foot
ft/s, foot per second
ft^3/s, cubic foot per second
in., inch
L, liter
lb/d, pound per day
$(lb/d)/mi^2$, pound per day per square mile
µm, micrometer
mg/L, milligram per liter
mg/m^2, milligram per square meter
mi, mile
mi^2, square mile
TU, U.S. Environmental Protection Agency toxicity unit

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Abstract

Data were collected at 10 stations in the Dickinson Bayou watershed near Houston, Texas, from March 1995 through February 1997 to estimate the concentrations, loads, and yields of selected nutrients that enter the bayou; to characterize the effects on nutrient concentrations of flow conditions, seasonality, and land use; and to identify nutrient sources (point or nonpoint) inferred from the occurrence and abundance of algal species in the benthic algal community. These data included rainfall samples, streamflow measurements, stream-water-quality samples, and biological samples, in addition to quality-assurance/quality-control samples.

Estimates of loads of selected nutrients for the 106-square-mile watershed during the study were made for point sources and nonpoint sources. Point-source loading data are available only for ammonia nitrogen. Approximately 21.3 pounds per day of ammonia nitrogen is estimated from point sources during the study period. Nonpoint-source loads are estimated for eight nutrient forms: 7.84 pounds per day of dissolved ammonia nitrogen, 5.79 pounds per day of dissolved nitrite nitrogen, 215 pounds per day of dissolved Kjeldahl nitrogen, 350 pounds per day of total Kjeldahl nitrogen, 40.1 pounds per day of dissolved nitrite plus nitrate nitrogen, 67.6 pounds per day of total phosphorus, 46.6 pounds per day of dissolved phosphorus, and 42.8 pounds per day of dissolved orthophosphate. Rainfall-deposition rates also are estimated for comparison with point- and nonpoint-source loads. Deposition rates are 110 pounds per day of dissolved ammonia nitrogen, 120 pounds per day of dissolved nitrate nitrogen, and 15.8 pounds per day of dissolved phosphorus.

Statistical tests were used to determine whether there are significant differences between nutrient concentrations during low-flow and during high-flow conditions. For basins with rural/mixed and urban land uses, nutrient concentrations generally are significantly different (greater) during storm events than during low flow, indicating accumulation in the watershed and subsequent washoff of nutrients. However, nutrient concentrations in storm-event samples consisting predominantly of runoff from a pasture are not significantly greater than those in low-flow samples. Statistical tests for seasonality indicate that dissolved ammonia nitrogen is significantly different in at least one season for all land uses (rural/residential, rural/mixed, and pasture) except urban. Concentrations tend to increase in the spring and early summer months, possibly from fertilizer application and subsequent washoff.

Constituent-yield data were used to make direct comparisons of the nonpoint-source load contributions from four stations with watersheds of different land use. These comparisons lead to three conclusions: (1) For all nutrient species except orthophosphate, urban land use is the largest nonpoint-source contributor, (2) Kjeldahl nitrogen is the most abundant nutrient species, and (3) organic nitrogen accounts for the major part of the Kjeldahl nitrogen.

Algal samples were collected at seven stations and were analyzed for periphyton identification and enumeration, and chlorophyll *a* and chlorophyll *b* concentrations. The large relative abundance of soil algae at stations in the middle

of the watershed likely indicates the cumulative effects on water quality of agricultural nonpoint sources. Farther downstream near the State Highway 3 bridge, and downstream of three major tributary inflows, the increase in abundance of soil algae to a larger-than-expected level might reflect water-quality influences from predominantly urban nonpoint sources in the drainage basins of the three major tributary inflows. Nutrient concentrations do not appear to limit algal production in the upper (non-tidal) reach of Dickinson Bayou; but nutrient concentrations could have been limiting benthic-algal production in the lower (tidal) reach of the bayou during the time of the synoptic survey. If nitrogen is the limiting resource for algal productivity in the tidal reach of Dickinson Bayou, eutrophication of the system could be (at least partially) mitigated if nonpoint-source nutrient loads into the Bayou were reduced.

INTRODUCTION

Nutrients are naturally occurring constituents that are necessary for plant and animal survival. The most important nutrients in aquatic environments are nitrogen and phosphorus. Nitrogen is present in water as nitrite and nitrate anions, in cationic form as ammonium (all inorganic nitrogen), and as part of organic solutes (Hem, 1992, p. 124). Organic nitrogen includes nitrogen present in peptides, proteins, nucleic acids, urea, and synthetic organic materials, as well as decay products from leaf litter, twigs, and other natural debris. The sum of organic nitrogen and ammonia can be determined analytically and is referred to as Kjeldahl nitrogen.

Phosphorus is not as abundant in the environment as nitrogen and often is the limiting element for plant growth. Usually phosphorus is present as phosphate in natural waters. Orthophosphate species are the predominant dissolved phosphorus forms in most streams (Terrio, 1995, p. 17). Much of the phosphorus in streams attaches to particulate matter and is unavailable for uptake by plants.

The nitrite and organic species of nitrogen are unstable in aerated water and generally are considered to be indicators of pollution from sewage or organic waste. However, not all organic nitrogen results from wastewater or animal wastes. Anionic species such as nitrate are readily transported in water and are stable over a considerable range of conditions. Ammonium cations are strongly adsorbed on mineral surfaces. The presence of nitrate or ammonium might be indicative of pollution from sewage or organic waste also, but generally the pollution would have occurred at a site or time substantially removed from the sampling point (Hem, 1992, p. 124).

Excessive nutrient levels can cause prolific algal growth and eutrophication, resulting in decomposition of plant and organic matter, increased oxygen demand, and fish kills. The Texas Natural Resource Conservation Commission (TNRCC) has defined screening levels for nutrients that reflect the concentrations at which nutrients could adversely affect water quality (for example, cause eutrophication). The screening level for both ammonia nitrogen and nitrite plus nitrate nitrogen is 1.0 mg/L in freshwater and 0.4 mg/L in saltwater (Texas Natural Resource Conservation Commission, 1996, p. 140–141).

Nutrient loadings to waterbodies often can be traced to point and nonpoint sources, including wastewater discharges and agricultural and urban stormwater runoff. Traditionally, environmental regulations have focused on controlling point sources (for example, wastewater discharges). Recently, nonpoint contributions have been recognized as potential sources of considerable nutrient loads (Terrio, 1995, p. 18). Water managers need information that can be used to determine the relative contributions from various point and nonpoint sources to make informed decisions about use of the resource.

Dickinson Bayou has been designated by the TNRCC as being “water-quality limited” (Texas Water Commission, 1992, p. 391). This designation means that stream-monitoring data indicate that surface-water-quality standards for stream segments of the bayou are not being met or advanced waste treatment for point-source wastewater discharges is required for the stream to meet applicable water-quality standards. Previous studies (Kirkpatrick, 1986a, b) have determined that nutrient concentrations are elevated throughout the bayou. Also, these studies indicated elevated fecal coliform densities, possibly related to numerous septic tanks in the watershed.

The U.S. Geological Survey (USGS), in cooperation with the Houston-Galveston Area Council (H-GAC) and the Texas Natural Resource Conservation Commission under the authorization of the Texas Clean Rivers Act, conducted a study of Dickinson Bayou to determine the relative contributions of selected nutrients from point and nonpoint sources. To obtain data necessary to estimate the values presented in this report, 166 water samples were collected from Dickinson Bayou and its tributaries and sent to the USGS National Water Quality Laboratory (NWQL) in Arvada, Colo., to be analyzed for selected nutrient concentrations; and 109 water samples were sent to the USGS sediment laboratory in Austin, Tex., to be analyzed for suspended-sediment concentration. Also, selected water samples were analyzed by the Galveston County Health District (GCHD) laboratory for biochemical oxygen demand (BOD) and fecal coliform bacteria, by the League City laboratory for toxicity using a microtox instrument (Microbics Corp., 1992), and by the U.S. Environmental Protection Agency (USEPA) laboratory for toxicity using 7-day survival and reproduction biomonitoring analysis (Plafkin and others, 1989). Measurements of temperature, specific conductance, pH, and dissolved oxygen were made in the field at the time of sample collection. Alkalinity titrations of selected samples were done at the USGS laboratory, Houston, Tex. Six bottom-sediment samples also were collected and sent to the NWQL to be analyzed for total forms of selected nutrients. Eight periphyton samples were collected and sent to the NWQL for chlorophyll *a* and chlorophyll *b* determinations, and eight additional samples were collected and sent to the NWQL for algal identification and enumeration (ID/enumeration). In addition to the environmental samples, 38 water samples were collected and sent to the NWQL for selected nutrient analyses for quality assurance/quality control (QA/QC). The water, bottom-sediment, and algae samples were collected at 10 locations in the watershed: 4 fixed stations and 6 synoptic-survey stations. These data were interpreted using graphical and statistical methods.

Purpose and Scope

The purpose of this report is to present estimates of concentrations, loads, and yields of selected nutrients that enter Dickinson Bayou from point and, particularly, nonpoint sources; to characterize selected properties and nutrients with regard to flow conditions, seasonality, and land use; and to develop a list of algal taxa present in the bayou and identify nutrient sources (point or nonpoint) inferred from the occurrence and abundance of algal species in the benthic algal community.

The report provides statistical summaries of data collected during the period March 1995 through February 1997. Nonpoint-source nutrient loads are computed for this period using the USGS Sediment-Record Calculations (SEDCALC) computer program (Koltun and others, 1994), which utilizes input files of streamflow and constituent concentration data to compute constituent loads (reported as pounds per day). Nonpoint-source nutrient yields (reported as pounds per day per square mile) are computed by dividing nutrient load by the area of the contributing subbasins. The Wilcoxon rank-sum test (Helsel and Hirsch, 1992) is used to determine whether there are significant differences in nutrient concentrations between data collected during low flow and during high flow. Similarly, the Kruskal-Wallis test (Helsel and Hirsch, 1992) is used to determine whether there are significant differences for data collected during different seasons and for data collected from subbasins of differing land use. Boxplots of nutrient concentration data also are presented to allow visual comparison of data collected from subbasins of differing land use.

Description of Study Area

Dickinson Bayou is about 25 mi southeast of Houston (fig. 1). The bayou is approximately 24 river mi long and is situated within Galveston County, although the westernmost part of the 106-mi^2 watershed is in Brazoria County (fig. 2). All or parts of the cities of Dickinson, Alvin, Friendswood, Santa Fe, League City, and Texas City lie within the watershed.

Dickinson Bayou flows eastward toward Dickinson Bay, a secondary bay of the Galveston Bay system. Dickinson Bayou is part of the San Jacinto-Brazos Coastal Basin and comprises two stream segments, as defined by the TNRCC. Segment 1104 is the Dickinson Bayou above-tidal reach, which flows 7.3 mi from Farm Road 528 to 1.2 mi downstream of Farm Road 517. Segment 1103 is the Dickinson Bayou tidal reach, which flows 16.4 mi from 1.2 mi downstream of Farm Road 517 to the Dickinson Bayou confluence with Dickinson Bay. Flow regimes in the two reaches are markedly different. The above-tidal reach is a relatively shallow stream (about 1- to 3-ft deep) with moving water, whereas the tidal reach is a predominantly deep channel (about 5- to 15-ft deep) with very sluggish flows. Also, streamside vegetation is different. The above-tidal reach is characterized by dense riparian vegetation that limits sunlight exposure (thus, photosynthesis), whereas vegetation in the tidal

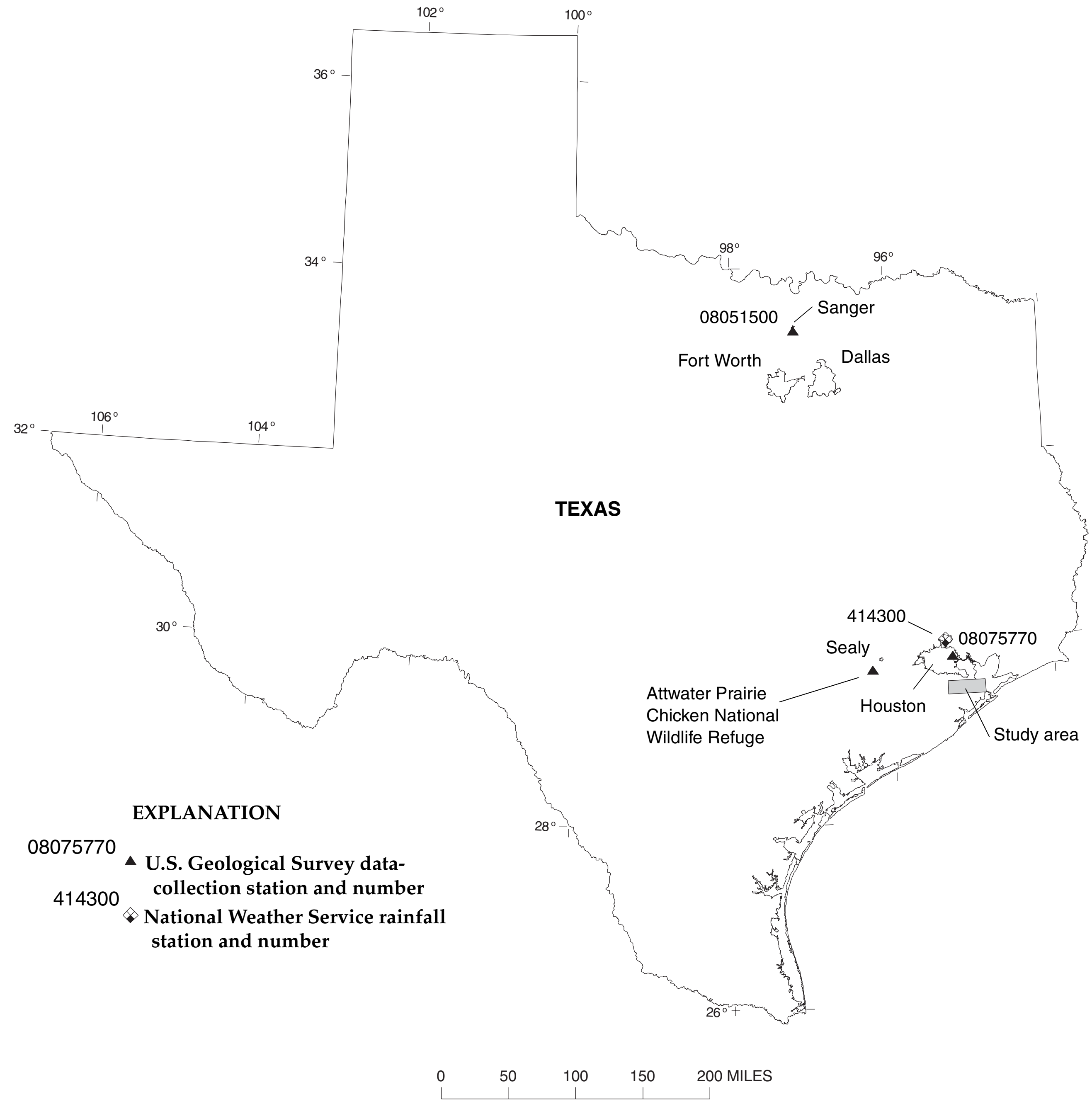

Figure 1. Location of study area and selected data-collection stations.

reach is less dense, which allows more exposure to sunlight.

Main tributaries to Dickinson Bayou are LaFlores Bayou, Cedar Creek, Runge Bayou, Drainage Ditch 9C, Drainage Ditch 12 (Thaman Draw), Bordens Gully, Magnolia Bayou, Benson Bayou, and Gum Bayou. Additionally, the Dickinson Bypass Channel parallels the upper bayou to the north before entering Cedar Creek (fig. 2).

The topography of the watershed slopes gently toward the bayou. Land-surface altitude varies from about 50 ft above sea level in the west to sea level at the mouth of the bayou. Soils primarily are clays or loams with low permeability.

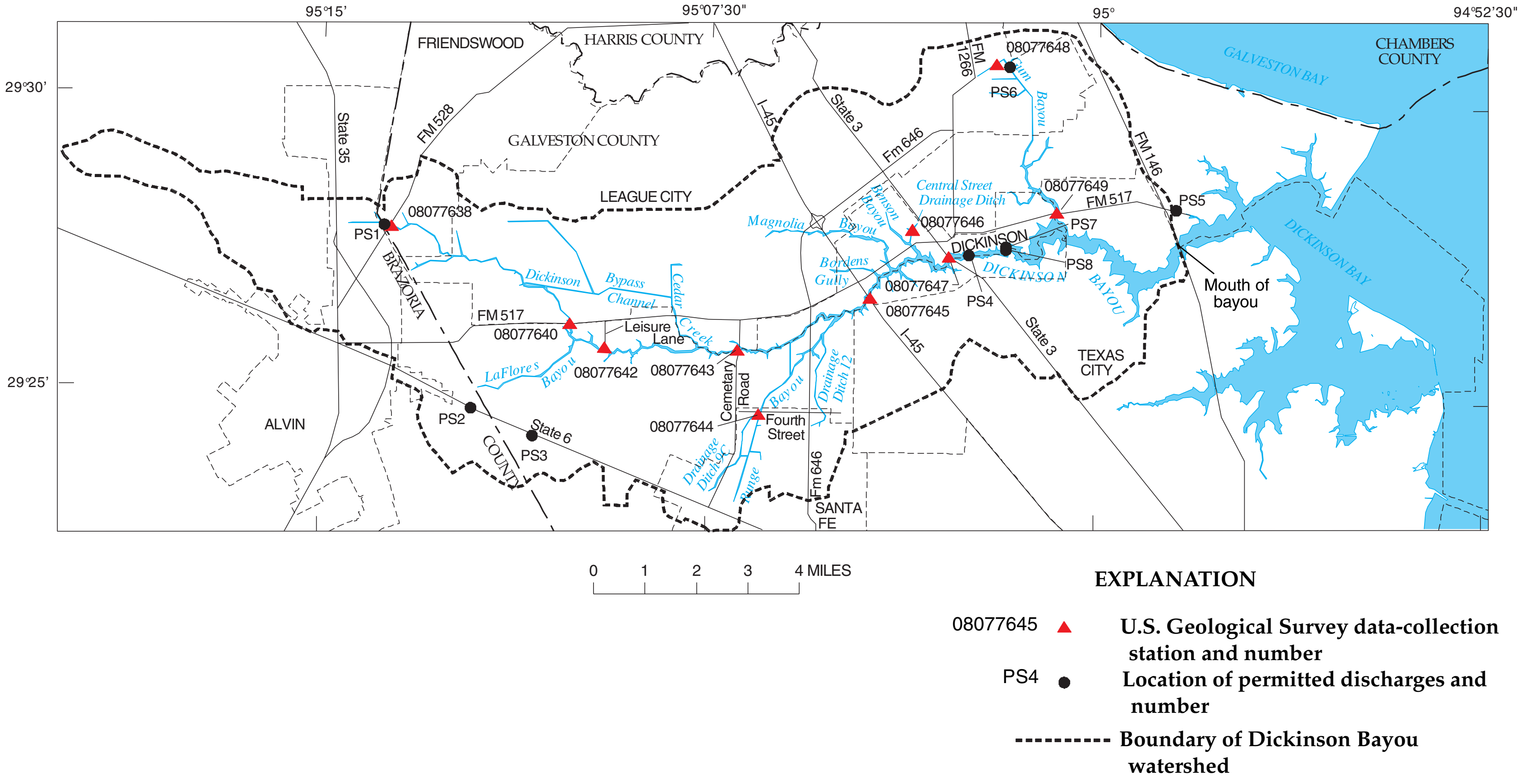

Figure 2. Dickinson Bayou watershed, data-collection stations, and permitted discharges in study area.

Land use varies from farmland and rangeland to concentrated residential and commercial development. The areas with the largest percentage of development are those in the vicinity of the cities of Dickinson and League City. For this study, four categories of land use were defined:

1. Rural/residential (RURAL/RES) - Areas of sparse human population with little or no presence of livestock. Typically, septic systems in use.
2. Rural/mixed (RURAL/MIX) - Areas of moderate human population, moderate presence of livestock, light commercial and agricultural use. Typically, septic systems in use.
3. Urban (URBAN) - Areas of dense human population with pockets of commercial and light industrial use. Few, if any, septic systems in use.
4. Pasture (PASTURE) - Areas of little or no human population with open rangeland, partly used for livestock grazing. Few septic systems in use.

On the basis of geographic information system (GIS) digital information (U.S. Geological Survey, 1990) and field inspections, approximately 10 percent of the basin is URBAN, 15 percent is PASTURE, and the remaining 75 percent is RURAL/RES and RURAL/MIX. The exact percentages for each of the rural classifications cannot be determined from available data, but field reconnaissance indicates that the majority of the basin is RURAL/MIX.

The climate of the study area is characterized by long, hot, and humid summers and mild winters. The average annual rainfall for the area is approximately 46 in., as determined from National Weather Service (NWS) records from the Houston Intercontinental Airport (IAH) rainfall station 414300 (National Weather Service, 1997), located approximately 20 mi northeast of downtown Houston. Typically, rainfall is distributed unevenly throughout the year, with most in the fall and spring.

Approximately 44 in. of rainfall were recorded at the IAH rainfall station during 1995, and 41 in. were recorded during 1996. However, during the majority of the data-collection period (March 1995–September 1996), southeast Texas was under drought conditions. The distribution of rainfall for January 1995–March 1997 is shown in figure 3. The drought is particularly evident during January–July 1996. Approximately 14 in. were recorded during this period, whereas the average for this period is 26 in.

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DATA COLLECTION

To collect the variety of data necessary to accomplish the objectives of the study, a multi-faceted data-collection strategy was used. Rainfall, streamflow, and stream-water-quality (sediment, nutrient, and biological) data were collected from March 1995 through February 1997 and supplemented with information collected by local and State agencies. Additionally, QA/QC samples were collected to ensure the adequacy of the methods used for data collection and data analysis. Water-quality samples were collected monthly, during storm events, and during low-flow and high-flow synoptic surveys.

Data were collected at 10 USGS stations during the study (table 1, at end of report). Four fixed stations consisted of semipermanent installations of streamflow-monitoring equipment and automatic water samplers. These stations were located on small streams and were used to measure runoff from small watersheds of fairly homogeneous land use. The land uses correspond to the four general categories previously listed. The stations were monitored regularly throughout the study period. In addition to the four fixed stations, six synoptic stations were located along the mainstems of Dickinson Bayou and Gum Bayou and were monitored less

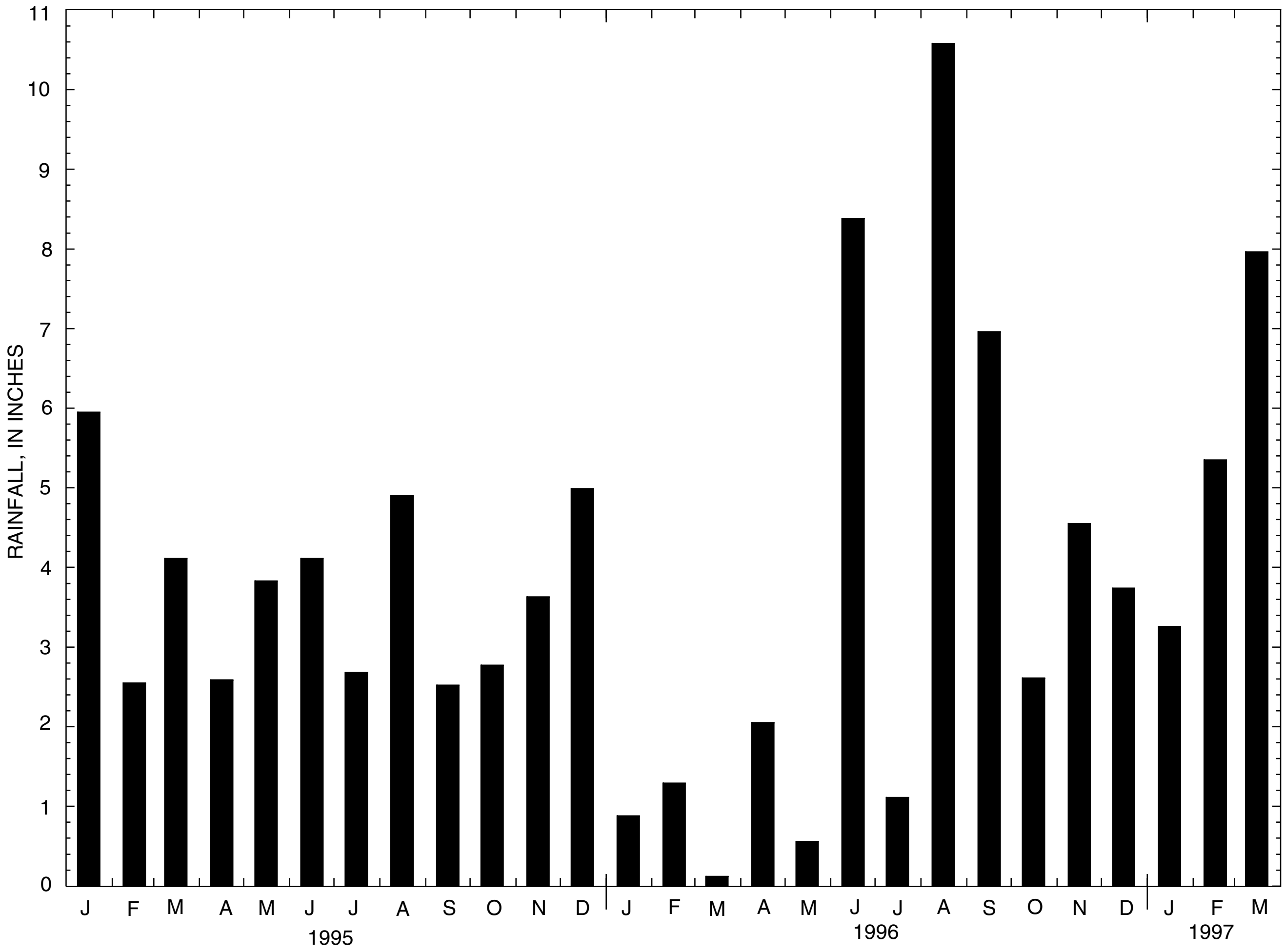


Figure 3. Monthly rainfall recorded by the National Weather Service at Houston Intercontinental Airport station 414300, January 1995–March 1997.

frequently than the four fixed stations. The sampling activities associated each type of data are listed in table 2 (at end of report).

Rainfall

Two rainfall samples were collected for water-quality analysis: 1 in June 1995 and 1 in June 1996. Both samples were collected at USGS station 08077646 (fig. 2). Rainfall samples were collected by removing the top of a standard USGS churn splitter and placing the bucket in an unobstructed position to collect rain. A churn splitter is a teflon bucket, with a churn and spigot, that is used to split large composite samples of water-sediment mixture into subsamples of a desired volume. When enough rain had accumulated in the bucket (typically, within 2 hours), the top was placed on the churn splitter, and a sample was collected. Rainfall samples were analyzed for total and dissolved forms of nutrients (table 2) by the NWQL.

Streamflow

During this study, instantaneous measurements of streamflow were made using standard USGS procedures documented by Rantz and others (1982). The measurements required division of a stream cross section into several subsections of known width, sounding the depth of flow for each subsection, and measuring the velocity of flow in each subsection. The product of width, depth, and velocity is the subsection streamflow. The sum of all subsection streamflows constitutes the total streamflow for the cross section.

Velocities were measured using either a Price pygmy or Price type AA velocity meter, depending on the depth of flow. When conditions allowed, wading measurements were made and top-setting wading rods were used to determine the depth of flow and to suspend the velocity meter in the water column. When depths of flow or velocities were too great, measurements were made by suspending instruments from nearby bridges to determine depths and velocities.

At the four fixed stations (table 1), pressure transducers were installed and gage-height data were electronically recorded by data loggers every 15 minutes. Gage height (stage) is defined as the water surface measured in feet above a local reference point, or “gage datum.” Streamflow measurements made at each station during various flow conditions were used to develop rating curves, which relate gage height to instantaneous streamflow. These rating curves were developed using standard USGS procedures outlined by Rantz and others (1982). By using the recorded gage-height data and the rating curves, 15-minute streamflow data were computed for each of the four fixed stations for March 1995–February 1997.

Water Quality

Water-quality samples were collected at the four fixed stations during 12 monthly site visits and during 8 storm events (table 2). Also, synoptic surveys were conducted during both low-flow and high-flow conditions. A synoptic survey involves the collection of water-quality data at multiple sites in a waterbody during a pre-determined hydrologic condition, over a specified period of time. The resulting data provide a “snapshot” of water-quality conditions for the waterbody during this hydrologic condition.

Field measurements of water temperature, specific conductance, pH, and dissolved oxygen were made. Water samples were analyzed in the laboratory for total alkalinity, BOD, fecal coliform bacteria, and toxicity. Additionally, eight nutrient forms were determined: dissolved ammonia as nitrogen, dissolved nitrite as nitrogen, dissolved ammonia plus organic nitrogen as nitrogen (dissolved Kjeldahl), total ammonia plus organic nitrogen as nitrogen (total Kjeldahl), dissolved nitrite plus nitrate as nitrogen, total phosphorus as phosphorus, dissolved phosphorus as phosphorus, and dissolved orthophosphate as phosphorus. Throughout this report, concentrations of each of these nutrients are expressed as concentrations of elemental nitrogen and phosphorus, respectively, in milligrams per liter, unless otherwise indicated. Also, there were several instances where constituent concentrations were reported by the laboratory as “below reporting level.” In these instances, the concentrations used for any subsequent computations were the minimum reporting level (MRL). Water samples also were analyzed for suspended-sediment concentration.

A low-flow synoptic survey was made on August 22, 1995. Flow measurements and water samples were collected from the six synoptic stations and from two of the four fixed stations (fig. 2; table 2). The two fixed stations that were not sampled (08077642 and 08077648) had no flow during this survey. Field measurements of temperature, specific conductance, pH, and dissolved oxygen were made. Water samples were collected using standard USGS methods and were analyzed in the laboratory for total alkalinity, BOD, fecal coliform bacteria, toxicity, total and dissolved forms of nutrients, and suspended sediment. Bottom-sediment samples also were collected from the six synoptic stations. These samples were analyzed for total forms of nitrogen (ammonia, Kjeldahl, and nitrite plus nitrate) and phosphorus.

During low-flow conditions (monthly and low-flow synoptic sampling), nutrient and alkalinity samples were collected using the equal-width-increment (EWI) method described by Wells and others (1990, p. 18). This method consists of collecting depth-integrated subsamples from 10 equal-width verticals in a given cross section and compositing them in a churn splitter. The churn splitter is used to thoroughly mix the subsamples before splitting the composite into the appropriate sample bottles. Samples for total nutrient analysis were drawn directly from the churn splitter and chilled, and samples for dissolved nutrient analysis and total alkalinity titrations were filtered through a 0.45-μm inert filter, using a peristaltic pump, before chilling.

The EWI method could not be used in very shallow streams. In very shallow streams, five to seven “grab samples” were collected by immersing a 1-L bottle at the estimated centroid of flow by hand. Each subsample was poured into a churn splitter, which was used to composite and thoroughly mix the sample before samples for total and dissolved analyses were bottled.

BOD, fecal coliform, and toxicity samples were each collected as grab samples by immersing a 1-L sample bottle at the estimated centroid of flow until enough sample volume was collected.

Suspended-sediment samples were collected using the EWI method. Each subsample was not poured into a churn splitter for compositing, but instead was sent individually to the laboratory. As before, when shallow flow conditions did not permit using the EWI method, a grab sample was collected by immersing a sediment bottle at the estimated centroid of flow.

A high-flow synoptic survey was conducted during January 27–29, 1997. During high-flow conditions (storm-event and high-flow synoptic sampling), samples were collected at each of the four fixed stations using automatic water samplers. These samplers, programmed to be activated by increases in water stage, collected four discrete samples during a storm event by pumping water from the stream through a 3/8-in.-diameter sampler hose into 1-L teflon bottles. The four samples were collected during the following flow conditions: (1) first flush or beginning of storm event, (2) rising limb of hydrograph as stage was increasing, (3) peak streamflow, and (4) recession limb as stage decreased to one-half of peak stage. Instead of compositing the four discrete samples, they were submitted individually to the laboratory and analyzed for concentrations of total and dissolved forms of nutrients and suspended sediment. The first-flush sample also was used to determine specific conductance, pH, total alkalinity, BOD, fecal coliform bacteria, and toxicity.

During the high-flow synoptic survey, storm-event samples also were collected manually at two additional stations (08077638 and 08077647) using the EWI method. The three discrete samples were collected at each station during the following flow conditions: (1) first flush or beginning of storm event, (2) peak discharge, and (3) recession limb as stage decreased. Each of these discrete water samples was analyzed for concentrations of total and dissolved forms of nutrients, as well as suspended sediment. The first-flush sample was used to determine specific conductance, pH, total alkalinity, BOD, fecal coliform bacteria, and toxicity.

Biological

During a low-flow synoptic survey, algal samples were collected at seven USGS stations (table 2) and analyzed by the NWQL for periphyton algal ID/enumeration, and for chlorophyll *a* and chlorophyll *b* concentrations. Algal ID/enumeration involves the identification of algal taxa in the sample, as well as quantifying the number of taxa. These data were used to assess the status of the biological community, in terms of population and diversity, and were collected during the low-flow survey because during low flow is when the system most likely would be stressed due to eutrophication (nutrient enrichment). Sampling protocols developed for the USGS National Water-Quality Assessment (NAWQA) Program were followed when collecting the algae (Porter and others, 1993).

Sampling conditions were normalized to minimize any variations in substrate among the different sampling stations. To normalize conditions, several standard sampling media (unglazed clay tiles) were placed at each station approximately 6 weeks before sampling. These tiles were situated in areas of similar velocity (estimated to be less than 0.5 ft/s during ambient flow) and depth (all within 6 to 12 in. of water). Depths could not be normalized closer than this because normal tidal fluctuations at the tidal-reach stations caused stage changes of at least 1 ft each day, whereas stage at the above-tidal-reach stations remained fairly constant. During the 6-week “incubation” period, no storm events occurred in the watershed.

Quantitative periphyton microalgae samples were collected using the NAWQA periphyton sampling device, the SG–92 (Porter and others, 1993, p. 14), which was used to remove algae from a known surface area of the sampling media. The resulting algae-water mixture was then withdrawn using a hand pipettor (noting the volume) and placed in a sample bottle. At a given station, this procedure was repeated using five to seven of the clay tiles. These five to seven subsamples were composited to form one sample of known surface area and volume.

Algal samples were collected at the six synoptic stations and one fixed station (table 2). In addition to the seven algae samples collected, another sample was collected at fixed station 08077644 for QA/QC. Each of the eight algal-water samples were split into subsamples. One subsample was submitted to the NWQL for periphyton algal ID/enumeration. The second subsample was filtered through a 0.7-µm glass-fiber filter and then submitted to the NWQL for chlorophyll *a* and chlorophyll *b* determinations.

Quality Assurance/Quality Control

To provide quality assurance and quality control, a Quality Assurance Project Plan (QAPP) was prepared and followed throughout all phases of the study. This plan detailed formal procedures to ensure the quality, precision, accuracy, and completeness of the data that were collected during the study. All participants were required to follow procedures outlined in the plan.

To provide QA/QC data, equipment blanks, field blanks, split samples, and concurrent samples were collected and sent to the NWQL for total and dissolved nutrient analyses, and the percentage of spike-sample recovery was computed for selected nutrient samples. Also, a concurrent field sample was collected and sent to the NWQL for algal ID/enumeration.

Equipment blanks assess the potential contamination associated with sampling and processing equipment. They are solutions of inorganic-free water poured or pumped through sampling equipment in the office before the start of a sampling trip. Fifteen sets of equipment blanks were submitted to the laboratory for total and dissolved nutrient analyses during the study.

Field blanks assess the potential sample contamination that could occur during field sampling and sample processing (cleaning procedures and cross contamination). The procedure is identical to that for equipment blanks, except that it is done after the sampler has been used and cleaned in the field. Seven sets of field blanks were collected and analyzed for total and dissolved nutrients.

Split samples are used to determine the analytical precision (reproducibility) for various constituents in an environmental sample matrix. They are prepared by partitioning a larger volume of already processed and preserved sample from one bottle into equal subsamples before submitting to the laboratory for analysis. Comparison of the two results defines the analytical reproducibility. Ten sets of split samples were collected and analyzed for total and dissolved nutrients.

Concurrent samples are two samples taken as close together in time and space as possible. They are intended to provide a measure of sampling precision (reproducibility) and to indicate inhomogeneities (spatial or temporal) in the system being sampled. Due to the nature of how the samples are collected, processed, and analyzed, differences due to both analytical (for example, laboratory analysis) and sampling imprecision are incorporated. Ten sets of concurrent samples were collected and analyzed for total and dissolved nutrients. Also, one additional periphyton microalgae sample was collected and analyzed for ID/Enumeration.

Spike samples are environmental samples fortified in the laboratory with a known concentration of all, or a representative selection of, the method analytes. The analytes are added in the laboratory immediately before sample preparation and analysis. The spike sample is used to verify method performance by recovery of the added analytes. Recovery reflects the bias from an environmental sample matrix plus normal method performance.

Commercial spike materials were available only for selected nutrient species. Therefore, analyses of spike samples were done only for dissolved ammonia nitrogen, dissolved ammonia plus organic nitrogen (Kjeldahl), dissolved nitrite plus nitrate nitrogen, total phosphorus, and dissolved orthophosphate. All spike-sample analyses were done at the NWQL. Twenty-five sets of spike samples were analyzed.

Data Compiled From Other Sources

The TNRCC and GCHD compile self-reported data for permitted discharges in the watershed. These data were obtained and used to estimate point-source nutrient loadings to the bayou. These agencies also collect water-quality data from Dickinson Bayou and its tributaries as part of their routine monitoring programs. The data from TNRCC and GCHD were compared with similar data collected for this study.

NUTRIENT LOADING

A constituent load for a stream is the product of a constituent concentration and streamflow and is the mass of a given constituent that is transported past a site on a stream during a specified period. The instantaneous load for a stream (Terrio, 1995, p. 38) is computed as

$$\mathrm{LOAD(i)} = \mathrm{FLOW(i)} \times \mathrm{CONC(i)} \times \mathrm{CF} \ , \quad (1)$$

where

LOAD = constituent load at time i, in pounds per day;
FLOW = discharge at time i, in cubic feet per second;
CONC = concentration of constituent at time i, in milligrams per liter; and
CF = conversion factor of 5.428.

Yield is a measure of the load-producing character of a subbasin and is computed by dividing load by the area of the contributing subbasin.

$$\mathrm{YIELD} = \frac{\mathrm{(LOAD)}}{\mathrm{(DA)}} \ , \qquad (2)$$

where

YIELD = constituent yield, in pounds per day per square mile; and
DA = area of contributing subbasin, in square miles.

Constituent yield data can be used to make direct comparisons of constituent contributions between subbasins.

Sources

Chemical constituents can enter a stream from various sources. For this report, three sources are considered: rainfall deposition, point sources, and nonpoint sources. Rainfall deposition occurs as chemical constituents attach themselves to raindrops (or small particulate matter) and are subsequently introduced into the watershed. Considerable amounts of nitrogen, particularly nitrates and ammonia, can be present in rainfall deposition. For example, during electrical storms, oxidized nitrogen bonds with atmospheric moisture to form nitrates that are brought to the ground in rainfall.

The National Atmospheric Deposition Program/National Trends Network (NADP/NTN) of the USGS operates a network of stations across the Nation where samples are collected to monitor atmospheric deposition. The NADP/NTN station nearest to Dickinson Bayou is at the Attwater Prairie Chicken National Wildlife Refuge, approximately 75 mi northwest of the city of Dickinson and 10 mi southwest of Sealy, Tex. (fig. 1). Data from this station were compared with laboratory analyses from two rainfall samples that were collected within the Dickinson Bayou watershed at station 08077646. Dissolved ammonia nitrogen concentrations compare closely, whereas nitrate nitrogen concentrations are appreciably larger in samples collected at the NADP/NTN site (table 3, at end of report). The differences could be a result of more rigorous sampling and analytical procedures used for rainfall samples collected at the NADP/NTN site, as well as differences in air quality and the amount of rainfall at the two stations.

Point sources consist of discharges of water or wastewater to streams through fixed structures that can be identified readily. Traditionally, water-quality assessments and pollution remediation efforts have been directed toward the control of point discharges. Point discharges usually are permitted outfalls and are monitored routinely.

At the beginning of the study, the Dickinson Bayou watershed had five permitted outfalls in segment 1103 (tidal reach) and three permitted outfalls in segment 1104 (above-tidal reach). The permittees are listed in table 4 (at end of report), and the location of the outfalls are shown in figure 2. The City of Friendswood - Towers Estate Plant in segment 1104 (Dickinson Bayou above-tidal reach) ceased operation in February 1996. Self-reported daily mean loads of ammonia nitrogen were obtained from the TNRCC and the GCHD.

Nonpoint sources consist of runoff to streams that results from storm events or ground-water discharge to streams. Chemical constituents that have accumulated on the land surface (for example, from fertilizer application) are washed into the natural drainage system of a watershed.

Streamflows and Concentrations

To determine nonpoint-source loads, constituent-concentration data and corresponding streamflow data were used. As discussed, daily mean streamflow was computed for the four fixed stations using recorded stage data and stage/discharge rating curves. Graphs of daily mean streamflow for the four fixed stations during the study period are shown in figure 4. Storm events sampled for each station are labeled.

Monthly Samples

Because the fixed stations are located on streams with small drainage areas (all less than 2.5 mi^2), monthly visits typically occurred during low-flow or no-flow conditions. The low-flow data were used to determine ambient levels of nutrients and other water-quality constituents, as well as to compute nutrient loads. Summary statistics of streamflow and water-quality data collected monthly at the four fixed stations are listed in table 5 (at end of report).

Storm-Event Samples

Data collected during the eight storm events (one event coincided with the high-flow synoptic survey) were used to determine the amount of nutrients present in nonpoint-source runoff and were used to compute nutrient loads. Summary statistics of water-quality data collected during the eight storm events at the four fixed stations are listed in table 6 (at end of report).

Low-Flow Synoptic-Survey Samples

Flow and water-quality data collected in Dickinson Bayou during a low-flow synoptic survey provide measures of loads in the bayou attributable primarily to point sources (at the time of sample collection) and ground-water (base-flow) discharge (Dunn, 1996, p. 3–4). Streamflow measurements, field measurements, and analytical results for selected

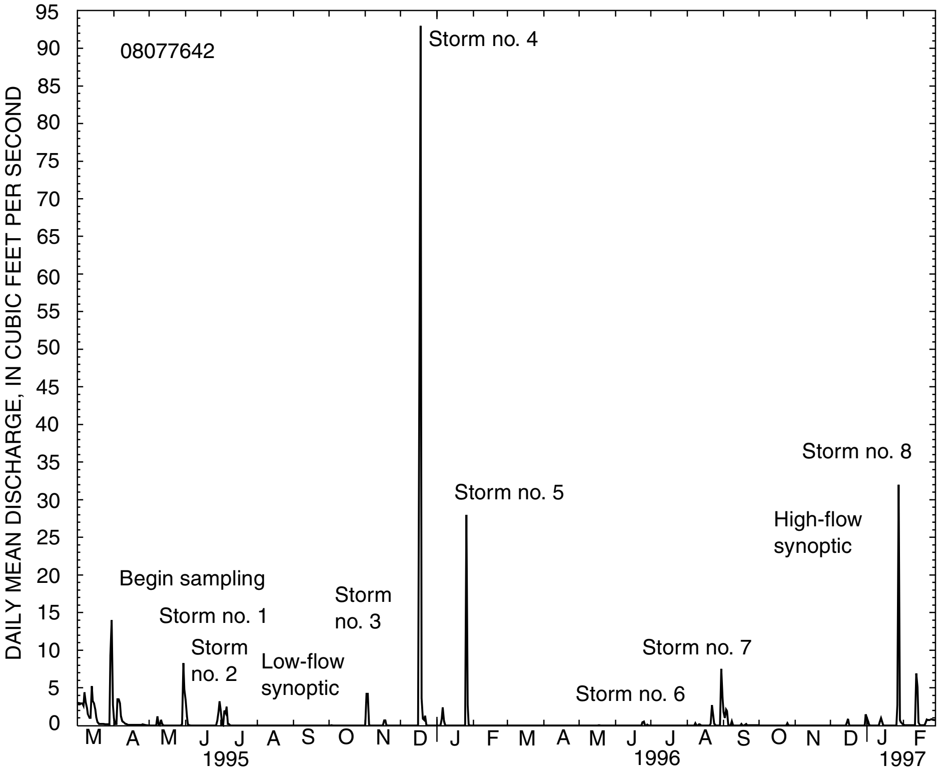


Figure 4a. Daily mean streamflow March 1995–February 1997 for station 08077642 drainage ditch at Leisure Ln. near Alvin, Texas.

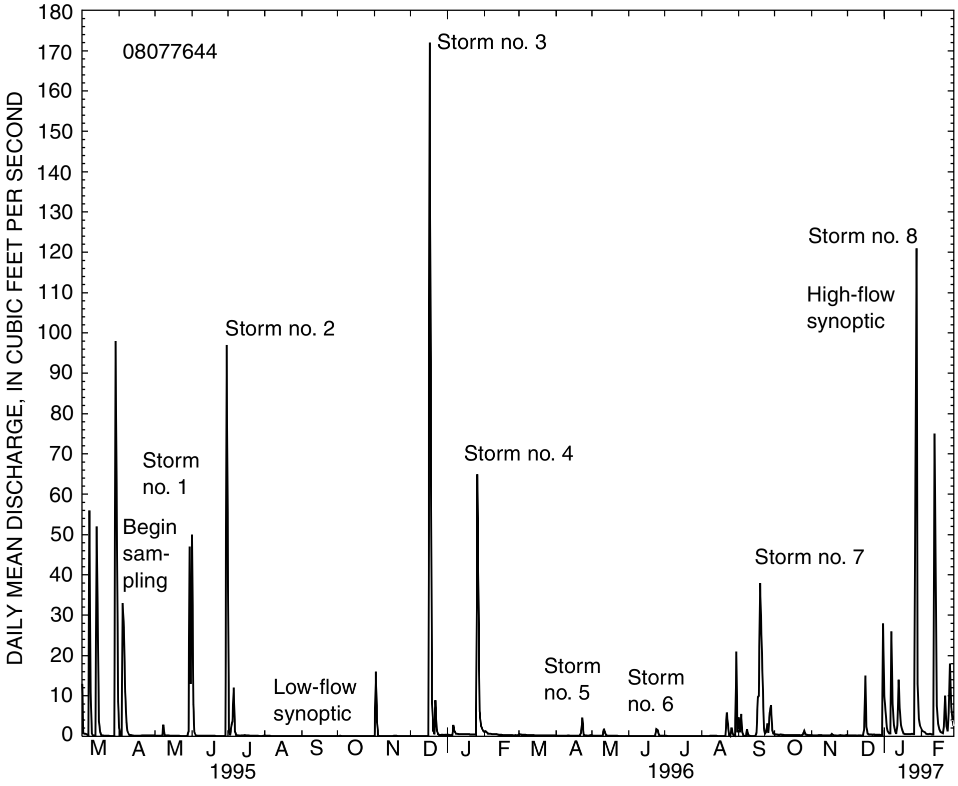


Figure 4b. Daily mean streamflow March 1995–February 1997 for station 08077644 Drainage Ditch 9C at Fourth St. near Santa Fe, Texas.

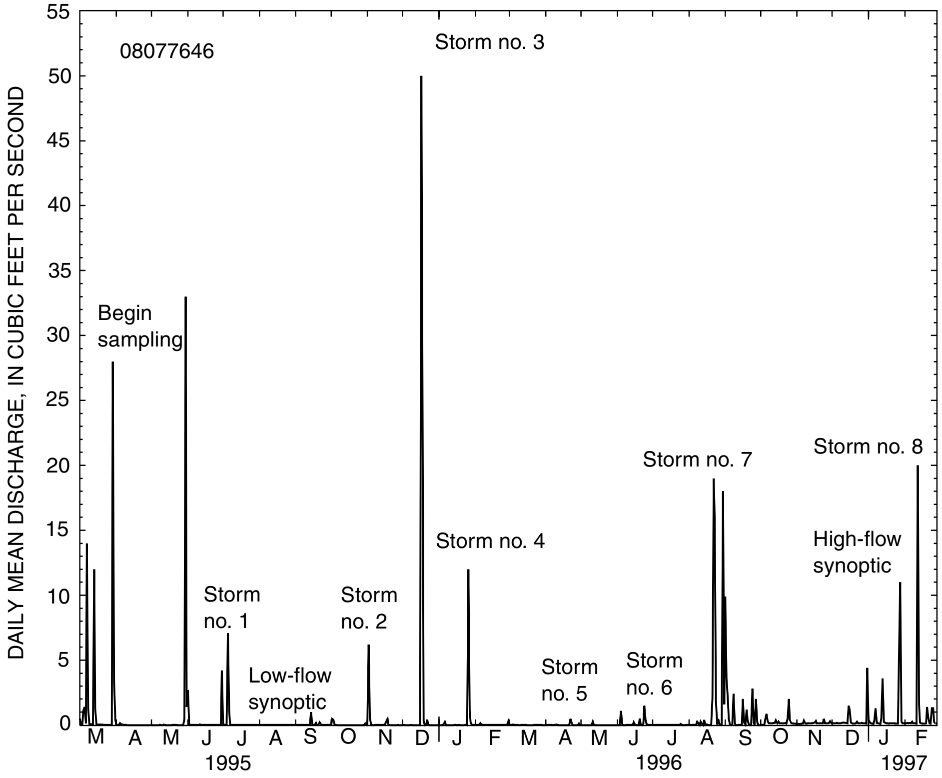


Figure 4c. Daily mean streamflow March 1995–February 1997 for station 08077646 Central St. Drainage Ditch at Dickinson, Texas.

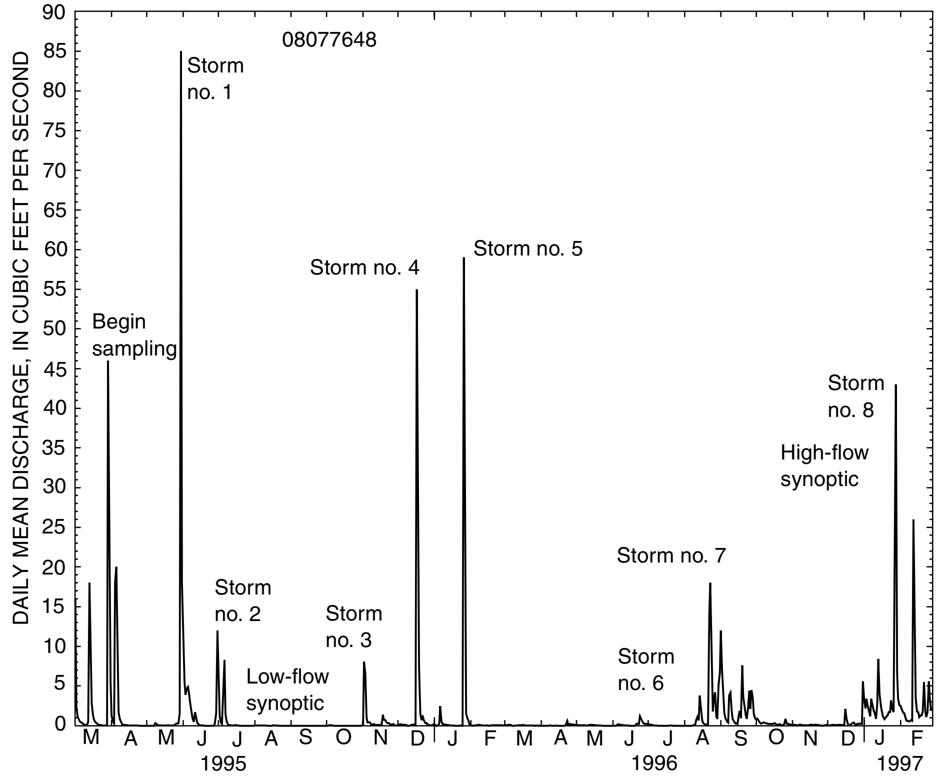


Figure 4d. Daily mean streamflow March 1995–February 1997 for station 08077648 Gum Bayou at Farm Road 1266 near League City, Texas.

water-quality properties are listed in table 7a (at end of report), and analytical results for nutrient and suspended-sediment concentrations are listed in table 7b. Concentrations of dissolved ammonia nitrogen and dissolved nitrite plus nitrate nitrogen were compared with TNRCC screening levels (Texas Natural Resource Conservation Commission, 1996, p. 140–141) to determine whether these constituents are elevated. During the low-flow synoptic survey, one constituent concentration exceeded the TNRCC screening level: The concentration of dissolved nitrite plus nitrate nitrogen for station 08077638 is 2.40 mg/L, which is larger than the screening level of 1.0 mg/L.

In this report, nutrients present in bottom sediments are not a defined source of loading to the bayou. However, such information does provide an indication of the amount of nutrients that previously have entered the system and have settled out of the water column. Dickinson Bayou is a slow-moving, sluggish system (especially in the lower reach), so considerable amounts of nutrients could settle out of suspension during low flow. These same nutrients might be resuspended during high flow and could be available for uptake by plants. Results of bottom-sediment analyses are listed in table 7c.

High-Flow Synoptic-Survey Samples

Data collected during the high-flow synoptic survey were used to quantify nutrient loads in Dickinson Bayou during a typical runoff event (when nonpoint-source contributions are predominant). Discharge measurements and water samples were collected by the automatic samplers at the four fixed stations and manually at two synoptic stations.

Analysis of data collected at the four fixed stations during the high-flow synoptic survey are included in table 6. Streamflow measurements, field measurements, and selected water-quality properties for the two synoptic-survey stations are listed in table 8a (at end of report). Results of laboratory analysis for nutrient and suspended-sediment concentrations for the two synoptic-survey stations are listed in table 8b.

Quality-Assurance/Quality-Control Samples

Fifteen equipment blank samples were collected and analyzed for total and dissolved nutrients. Twelve concentrations from the nutrient analyses are larger than the MRL for the given constituents. Of the 12, only 2 concentrations are as much as 0.05 mg/L larger than their respective MRL—total and dissolved Kjeldahl nitrogen concentrations in samples collected on May 24, 1995. Control charts from the NWQL (charts documenting QA/QC data for the entire laboratory) show that analyses for Kjeldahl nitrogen using laboratory blanks were within acceptable limits (within 0.15 mg/L) on the day of analysis (May 31, 1995). Further, environmental samples collected and analyzed on the same days (May 24 and May 31, 1995, respectively) do not show larger concentrations of total or dissolved Kjeldahl nitrogen than samples from other days. The cleaning procedures used before sampling trips were judged to be sufficient to prevent sample contamination.

Similar results were determined from the collection and analyses of seven sets of field blanks. Only four concentrations exceed their respective MRL for the various nutrient analyses. Each of the four are within 0.01 mg/L of the MRL. The cleaning procedures used during field sampling and processing also were judged to be sufficient to prevent sample contamination.

Ten sets of split samples were collected and analyzed for total and dissolved nutrients to assess the analytical precision of the laboratory. In 16 instances the computed relative percent difference (RPD) between the environmental sample and the split sample exceeds 20 percent, the maximum acceptable limit in the study QAPP. However, upon closer examination, the absolute magnitudes of the differences range from 0.05 to 0.30 mg/L, which are small in terms of absolute constituent concentration. Thus, the large RPDs are believed to be primarily the result of small constituent concentrations. Further, laboratory control charts from the NWQL for the 1995–96 water years show that analytical results for each of the nutrient species were almost always within acceptable tolerances (30 percent) in terms of duplicate precision. Therefore, even though there are instances when computed RPDs exceed the stated objective of 20 percent, laboratory analytical precision was judged to be acceptable.

Ten concurrent samples were collected and analyzed for total and dissolved nutrients to assess analytical and sampling precision. Fifteen computed RPDs are larger than the stated limit of 20 percent. As was the case with the split samples, the high RPDs are believed to be more a result of the small nutrient concentrations than an indication of poor reproducibility. The absolute differences in concentration, which range from 0.01 to 0.20 mg/L, are small. Concurrent samples measure both analytical and sampling precision, while split samples measure only analytical precision. Therefore, it is likely that some of the RPDs computed for the concurrent samples are due to sampling imprecision. On the basis of the small differences in concentration for concurrent samples, sampling precision was judged to be within acceptable limits.

Twenty-five sets of spike samples were analyzed. Of these, only three have recoveries of analytes below 85 percent, which was the stated objective in the project QAPP. There are two below-minimum recoveries for total phosphorus (82.5 and 82.25 percent) and one for dissolved Kjeldahl nitrogen (84.15 percent). However, laboratory analyses for each of these constituents were done using a multi-step procedure (pipetting and digesting), which could explain part of the variance. All other recoveries were 85 percent or more, indicating that laboratory methods for nutrient analysis are adequate in terms of analyte recovery.

Loads

Streamflow and water-quality data were collected during March 1995 through February 1997. Estimated nutrient loads and yields to the bayou during this period from point and nonpoint sources were computed. Estimated rates of atmospheric deposition (reported as pounds per day) also were computed during this period to compare with point- and nonpoint-source loads.

Rainfall Deposition

Rainfall amounts recorded at the NWS IAH station and the mean concentrations of selected nutrients in rainfall samples from USGS streamflow-gaging station 08077646 and from the NADP/NTN station near Sealy (table 3) were used to estimate rates of atmospheric deposition, in pounds per day, of the selected nutrients to the Dickinson Bayou watershed. Point rainfall amounts recorded at IAH were adjusted to areal rainfall amounts using methods developed by the NWS (Hershfield, 1961). Deposition rates were computed for dissolved ammonia nitrogen, dissolved nitrate nitrogen, and dissolved phosphorus for the 2-year study period. Rates computed on the basis of concentration data from station 08077646 are 110 lb/d of dissolved ammonia nitrogen, 120 lb/d of dissolved nitrate nitrogen, and 15.8 lb/d of dissolved phosphorus. Deposition rates computed on the basis of concentration data from the NADP/NTN station are 108 lb/d of dissolved ammonia nitrogen and 413 lb/d of dissolved nitrate nitrogen. (No phosphorus rate was computed because the single available concentration was less than the MRL.)

The large difference between dissolved nitrate nitrogen deposition rates at the two stations is due to the large difference between mean nitrate concentrations. This difference between concentrations could be caused by more rigorous sampling procedures followed by NADP/NTN for rainfall sampling and analysis or by differences in air quality between the two locations.

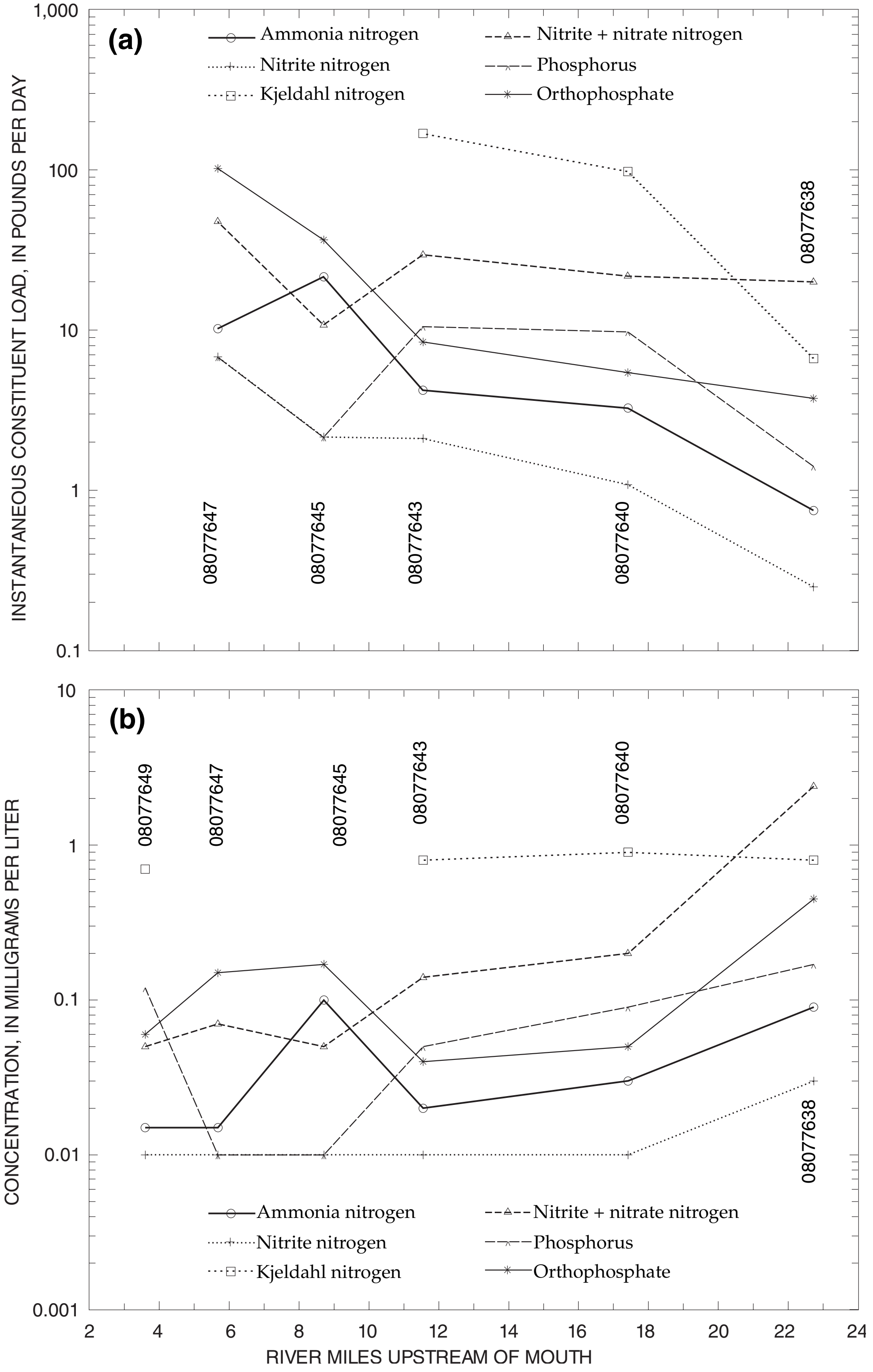
Point Source

Estimated loads of ammonia nitrogen from each of the eight permitted discharges in the watershed were computed for the 2-year project period from daily mean loads reported by the permittees (Texas Natural Resource Conservation Commission, Galveston County Health District, Water Collection Improvement District No. 1, written commun., 1997). Ammonia nitrogen is the only nutrient for which point-discharge data are available. About 21.3 lb/d of ammonia nitrogen was released to the bayou from the eight point-discharge sources during the 2 years.

Instantaneous nutrient loads and the component concentrations and instantaneous streamflow during the low-flow synoptic survey are shown in figure 5 by station, as a function of upstream distance from the mouth of Dickinson Bayou. Typically, during low-flow conditions, nutrient loads are attributable primarily to point sources and ground-water discharge (Dunn, 1996, p. 3–4). Although concentrations of most of the dissolved nutrients tend to decrease in a downstream direction, nutrient loads increase. This relation primarily is caused by increased streamflow in the lower sections of the bayou. Kjeldahl nitrogen concentrations do not show a decreasing trend in the downstream direction, but Kjeldahl nitrogen loads did increase in a downstream direction.

Nonpoint Source

An approach that commonly is used to compute suspended-sediment loads was used to determine nutrient loads from the drainage areas of the four fixed stations for the study period. (No known point sources are in the drainage areas of the four fixed stations.) The USGS Sediment-Record Calculations (SEDCALC) computer program (Koltun and others, 1994) systematically computes constituent loads using input files of streamflow and constituent concentration data. The program uses a form of equation 1 to compute constituent load for each of a series of time steps. Then the load for each time step is summed to obtain the total load.



Note: Station 08077649 not included in figure 5a because station is about 0.25 mile upstream of Dickinson Bayou, and loads there are not representative of loads in the bayou

Figure 5. (a) Instantaneous loads and (b) concentrations of dissolved species of nitrogen and phosphorus, and (c) instantaneous streamflow for selected stations, Dickinson Bayou near Houston, Texas, during low-flow synoptic survey August 22, 1995.

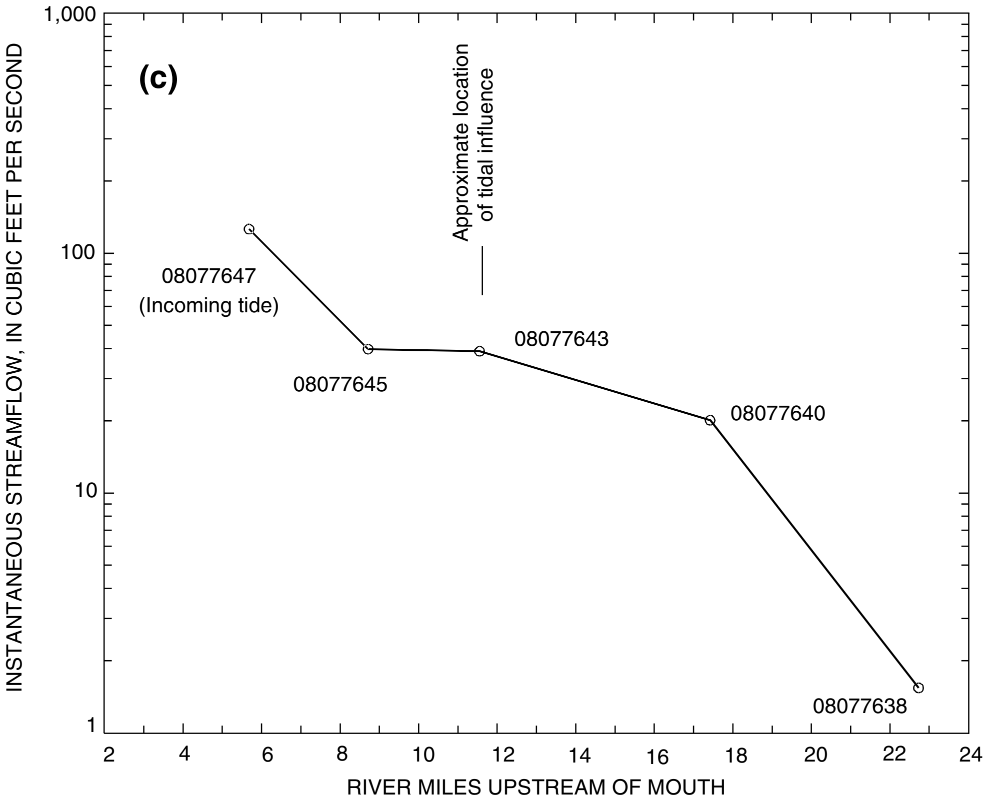


Figure 5.—Continued.

At the four fixed stations, streamflow data were computed at 15-minute intervals; constituent concentration data were only available from monthly sampling and storm-event sampling. SEDCALC linearly interpolates between the 15-minute streamflow values, which might be a reasonable approximation for the small streams, as they typically did not exhibit rapid changes in flow (increased less than 25 ft^3/s in 15 minutes). However, for this study, concentration data were separated in time by much longer intervals (days, weeks, or even months), so linear interpolation between these data points was not always appropriate. Also, samples were not collected during all rainfall-runoff events. Therefore, estimated concentrations for the various constituents were entered into the data sets. Samples were collected during each quarter of the calendar year; thus, all seasons were represented.

To estimate concentrations, it was assumed that concentration data could be grouped by flow condition; low flow (monthly samples), storm-event rising limb (storm beginning to peak flow), and storm-event recession limb (peak flow to base flow). Concentration data for each of the four stations were grouped in this manner, and the medians of these groups were computed and entered into the input files as appropriate. For instance, for any storm events when samples were not collected, four estimated values were added to the file as (1) low-flow median placed just before the beginning of the storm, (2) rising-limb median placed at the hydrograph peak, (3) recession-limb median placed when base flow was reached, and (4) low-flow median placed 24 to 48 hours after base-flow conditions were reached.

Once the input data sets were compiled, SEDCALC was used to compute daily loads of the selected nutrients at each of the four fixed stations. In each instance, the daily loads were summed and divided by the number of days in the 2-year study period (731) to compute a daily mean load. Yields for each of the constituents were then computed for each of the four fixed stations using equation 2. Dissolved organic nitrogen yield was estimated by subtracting dissolved ammonia nitrogen yield from dissolved Kjeldahl nitrogen yield. Computed loads and yields for the stations for the study period are listed in table 9 (at end of report).

Estimated yields of total nitrogen (sum of total Kjeldahl nitrogen and dissolved nitrite plus nitrate nitrogen) at the four fixed stations range from about 3.85 to 6.43 (lb/d)/mi^2 and total phosphorus yields range from about 0.156 to 1.21 (lb/d)/mi^2. The ratio of total nitrogen yield to total phosphorus yield was computed for each station. Station 08077648 has a ratio of 26 to 1; stations 08077642, 08077644, and 08077646 have ratios of 7.9, 4.3, and 5.3 to 1, respectively. Nitrogen is present in larger amounts than phosphorus in aquatic systems (Hem, 1992, p. 128). A small ratio (less than 10 to 1) of nitrogen to phosphorus yield can indicate that the amount of phosphorus in nonpoint-source runoff is elevated at a station. Past studies by TNRCC (Kirkpatrick, 1986a, b) have shown elevated phosphorus levels in Dickinson Bayou.

Constituent-yield data were used to make direct comparisons of the nonpoint-source load contributions from the basins of the four fixed stations. Computed nutrient yields for each of the four stations (table 9) were used to develop pie charts to show the relative nonpoint-source contribution of selected nutrients from each of the four land uses represented by the four fixed stations (fig. 6). The size of each circle in figure 6 indicates the relative constituent yield in pounds per day per square mile.

Three conclusions can be drawn from the pie charts: (1) For all nutrient species except orthophosphate, URBAN land use is the largest nonpoint-source contributor, (2) Kjeldahl nitrogen is the most abundant nutrient species, and (3) organic nitrogen accounts for a major part of the Kjeldahl nitrogen.

During the high-flow synoptic survey January 27–29, 1997, concentration data were collected at two stations along Dickinson Bayou: 08077638 and 08077647 (table 8). Loads primarily attributable to nonpoint-source runoff were estimated for the 3-day period. For comparison of nutrient loads attributable to nonpoint sources with nutrient loads attributable primarily to point sources, estimates of loads for a typical 3-day low-flow period were computed using flow and constituent data collected during the low-flow synoptic survey (table 7). The bar graphs in figure 7 show that, for each of the two stations, nutrient loads are larger during storm events than during low-flow periods. Estimated nonpoint-source loads at each station for the 3-day period are at least twice the estimated point-source loads. Also, it is evident that nutrient loads for the downstream station are larger than loads for the upstream station, which is attributed to increased stream discharge at the downstream station.

Estimates of nonpoint-source loads of selected nutrients from the entire Dickinson Bayou watershed also were computed by assuming that the water quality of runoff from areas of similar land use is similar. This assumption allows the constituent yields computed for the four fixed stations, each of which represents one of the four types of land use, to be used for all other areas in the watershed with the same respective land use. For instance, the nutrient yields computed for urban areas could be multiplied by the entire watershed area designated as urban to produce estimates of the total nutrient load contributed by urban areas. The entire watershed was subdivided into general areas of similar land use as determined from large-scale (1:250,000) GIS land-use data. The land-use subdivisions were refined by field reconnaissance. The yields were multiplied by the corresponding drainage areas to compute total constituent loads for the 2-year study period. For each subdivision, the loads (the products of yield times drainage area) were summed to obtain total nutrient loads to the bayou from nonpoint sources. Daily mean loads were then computed by dividing the total loads by the number of days (731) in the study period (table 10, at end of report).

WATER-QUALITY CHARACTERISTICS

Properties, Biochemical Oxygen Demand, Fecal Coliform Bacteria, and Toxicity

Water-quality properties vary in the reaches of Dickinson Bayou, as shown by graphs of instantaneous temperature, specific conductance, pH, and dissolved oxygen versus distance upstream from the mouth of Dickinson Bayou (fig. 8). The data were collected during the low-flow synoptic survey. The three upstream stations (08077638, 08077640, and 08077643) are not affected by tides, and the three downstream stations (08077645, 08077647, and 08077649) are affected by tides, which is evident from the graph of specific conductance. The dissolved oxygen graph shows that stations in the above-tidal reach of the bayou (characterized by shallow, flowing waters) have larger dissolved oxygen concentrations than stations in the tidal reach (characterized by deep, sluggish waters). Previous studies (for example, Kirkpatrick, 1986a, b) have reported small dissolved oxygen concentrations in the lower reaches of Dickinson Bayou.

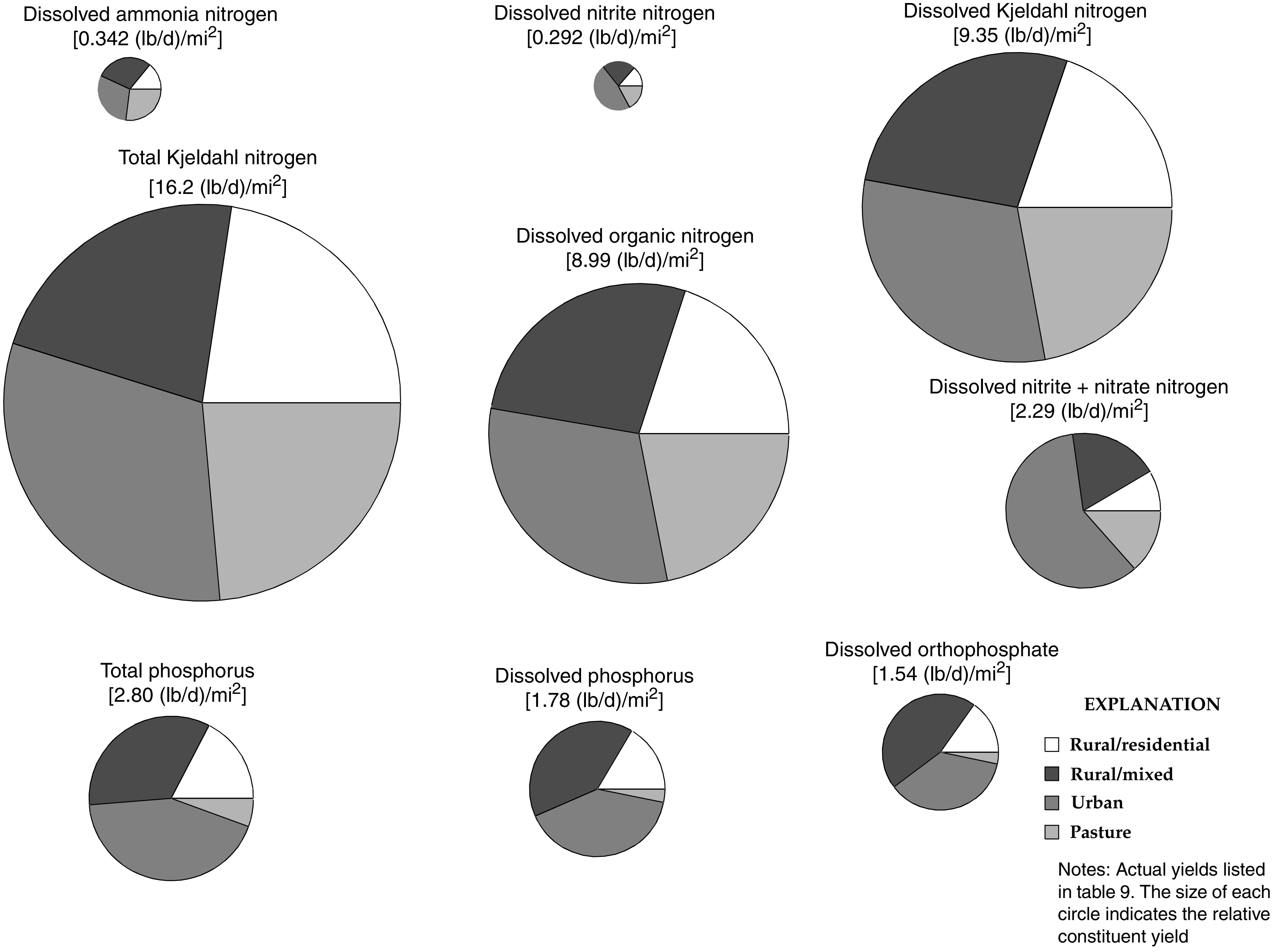


Figure 6. Estimated yields of selected nutrients from four watersheds, each with a different land use, Dickinson Bayou near Houston, Texas, March 1995–February 1997.

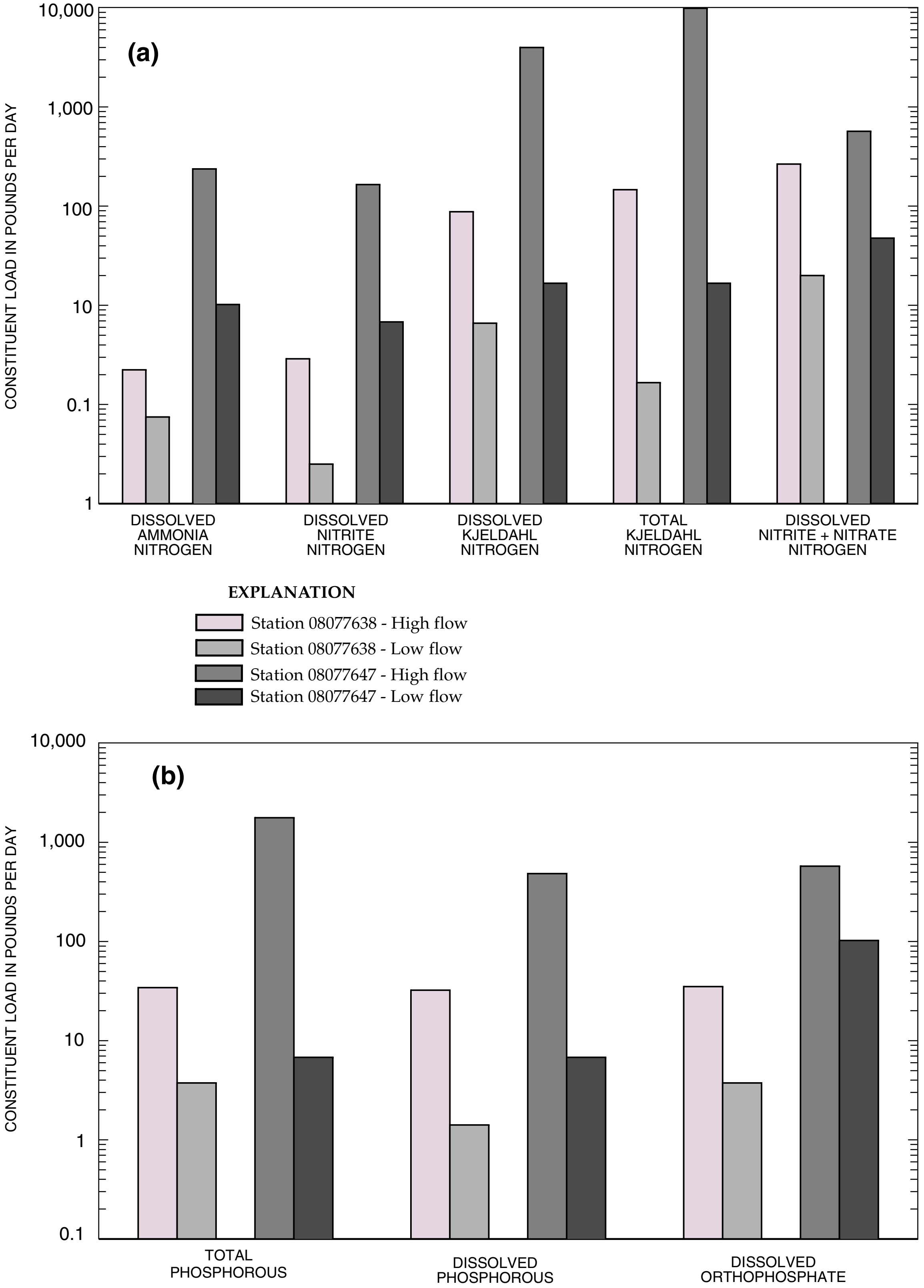


Figure 7. Comparison of loads of selected (a) nitrogen species and (b) phosphorus species during low-flow synoptic survey August 22, 1995, and high-flow synoptic survey January 27–29, 1997, for stations 08077638 and 08077647, Dickinson Bayou near Houston, Texas.

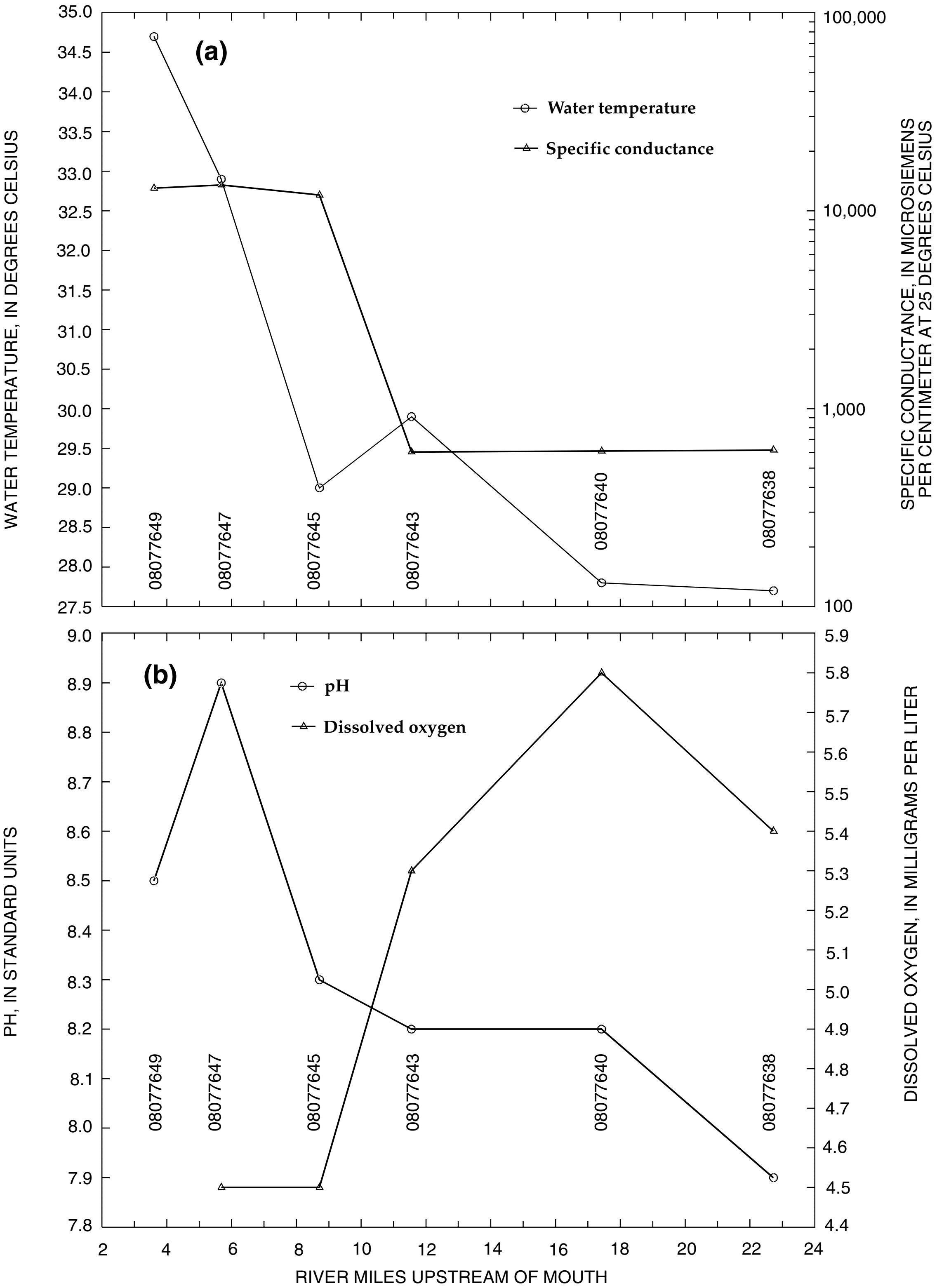


Figure 8. Instantaneous (a) water temperature and specific conductance and (b) pH and dissolved oxygen for selected stations, Dickinson Bayou near Houston, Texas, during low-flow synoptic survey August 22, 1995.

BOD expresses organic stream-pollution loads and is useful in comparing one set of conditions with another (Hem, 1992, p. 158). BOD of samples collected during low-flow conditions (table 5) range from 1 to 5 mg/L, and BOD of samples collected during storm events (table 6) range from 3 to 10 mg/L.

Fecal coliform bacteria can indicate water that has been contaminated with feces of humans or other warm-blooded animals (Viessman and Hammer, 1985, p. 239). Water samples for bacteria analysis were collected monthly and during storm events. The amount of fecal coliform bacteria increases appreciably during storm events (table 6), relative to low-flow (monthly) conditions (table 5). The increase could be the result of animal feces being washed off during storm events.

Recent studies by the Galveston County Health District (written commun., 1997) also have shown elevated densities of fecal coliform bacteria in Dickinson Bayou. Ten samples were collected during a 30-day period at three locations along the bayou: Cemetary Rd. (station 08077643), State Highway 3 (station 08077647), and State Highway 146. Geometric means of these samples were computed as 239 cols./100 mL at Cemetary Rd., 269 cols./100 mL at State Highway 3, and 85 cols./100 mL at State Highway 146. The Texas Administrative Code (Title 30, Ch. 307) states that for contact recreation waters (1) the fecal coliform density shall not exceed 200 cols./100 mL as a geometric mean based on a representative sampling of not less than five samples collected over not more than 30 days; and (2) fecal coliform density shall not equal or exceed 400 cols./100 mL in more than 10 percent of all samples based on at least five samples collected during any 30-day period. Samples collected at Cemetary Rd. and at State Highway 3 failed both of these criteria, while samples collected at State Highway 146 met both criteria. The GCHD hypothesized that the elevated bacteria concentrations at Cemetary Rd. and State Highway 3 might be due to agricultural wastes, poorly performing septic systems, wastes from pets, or exfiltration from wastewater collection systems.

Toxicity is an empirical measure of adverse effects on aquatic life, typically fish, caused by exposure to a water sample. Effects include behavioral changes, as well as mortality. The higher the toxicity, the more likely the fish are to be adversely affected by the water. Toxicity can be caused by a variety of factors. During the study, measurable toxicity was reported for only one of the samples analyzed by the League City laboratory microtox instrument (Microbics Corp., 1992), 1.76 TU in a monthly sample collected at station 08077642. All other monthly and storm-event samples yielded no toxicity “hits.” Also, samples collected during the low-flow synoptic survey and subjected to USEPA 7-day survival and reproduction biomonitoring analysis (Plafkin and others, 1989) indicated no measurable toxicity.

Nutrient Concentrations Based on Selected Factors

Statistical and graphical comparisons were made to assess differences in concentrations of selected nutrients for the four fixed stations resulting from different flow conditions, changes in seasons, and different land uses.

Flow Conditions

Statistical tests were used to determine whether there are significant differences in concentration between data collected during low-flow and during high-flow conditions. For three stations (08077644, 08077646, 08077648), the nutrient data were aggregated by flow condition into two groups—those samples collected during low flow (monthly sampling) or during high flow (storm-event sampling). Data from station 08077642 were not used because there was only one monthly sample.

The Wilcoxon rank-sum test (Helsel and Hirsch, 1992, p. 118) was used to test whether one group tends to produce larger observations than the second group. The test is a nonparametric (that is, the data do not have to be normally distributed) hypothesis test. The null hypothesis is that the two groups come from the same population. The alternative hypothesis is that the two groups come from different populations—specifically, that the high-flow (storm-event) concentrations are larger than the low-flow (monthly) concentrations. The test yields a p-value[1] that is compared with a pre-determined level of significance (α) to determine whether there is sufficient evidence to reject the null hypothesis. If the computed p-value is less than the level of significance, there is sufficient evidence and the null hypothesis is rejected. The test is a one-sided hypothesis test in this application

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[1] The p-value is the “attained significance level” (the significance level attained by the data), which is the probability of obtaining the computed test statistic, or one even less likely, when the null hypothesis is true (Helsel and Hirsch, 1992, p. 108).

because it was expected before the test that storm-event concentrations, if different from monthly concentrations, likely would be larger than monthly concentrations. An α of 0.05 (which is commonly used for hypothesis testing) was chosen as the level of significance. Thus, if the null hypothesis is rejected (indicating that the two groups are different) on the basis of a p-value less than 0.05, there is a 95-percent certainty that the two groups are different.

For station 08077644, the one-sided null hypothesis was rejected (at the 0.05 level) for all eight nutrient species; at station 08077646, the one-side null hypothesis was rejected for dissolved nitrite nitrogen, total Kjeldahl nitrogen, dissolved nitrite plus nitrate nitrogen, total and dissolved phosphorus, and dissolved orthophosphate (table 11, at end of report). These test results indicate that concentrations of all eight nutrients at station 08077644 and six of the eight at station 08077646 are larger during storm events (nonpoint-source loading) than during low-flow conditions. Land use of these two basins are classified as RURAL/MIX and URBAN, respectively, with each exhibiting some effects of human activities. The increased nutrient concentrations during storm events indicate that there is some accumulation of the selected nutrients between storm events.

For station 08077648, the null hypothesis was rejected only for total and dissolved Kjeldahl nitrogen. These results indicate that for the other nutrients, the concentrations are not significantly different during low-flow and high-flow conditions. Therefore, there does not appear to be appreciable accumulation and washoff of nutrients from pastures, which is reasonable because man-made sources of nutrients (that is, fertilizers) typically are not applied to pastures. Although the Kjeldahl nitrogen concentrations are significantly greater during storm events, dissolved ammonia nitrogen concentrations are not. Therefore, it is most likely that the only constituent that is significantly different is organic nitrogen, which can result from the accumulation and washoff of animal waste and decayed vegetation.

Seasonality

Seasonality of nutrient concentrations (differences that are highly correlated to the time of the year) also was investigated through hypothesis testing. The seasons are defined as winter—December, January, and February; spring—March, April, and May; summer—June, July, and August; fall—September, October, and November.

The Kruskal-Wallis hypothesis test was used for nutrient concentrations from each fixed station to determine whether there are significant differences for data collected during different seasons. Because several of the stations had periods of no flow during some months, the number of monthly samples collected at each station varied. To eliminate any differences in the data sets caused by missing data, only those data collected during storm events were used for this analysis.

The Kruskal-Wallis test is a nonparametric test, similar to the Wilcoxon rank-sum test, extended to more than two groups. The test compares the medians of groups differentiated by one explanatory variable to determine whether all groups have the same median, or whether at least one median is different (Helsel and Hirsch, 1992, p. 159). As with the Wilcoxon rank-sum test, a p-value is computed and compared with a chosen level of significance to determine whether to accept or reject the null hypothesis. Again, a level of significance of 0.05 was chosen. Therefore, when a p-value of less than 0.05 was computed, the null hypothesis was rejected in favor of the alternative hypothesis. The null hypothesis for this test is that the medians of each group are identical, and the alternative hypothesis is that at least one of the groups has a different median. The Kruskal-Wallis test in this application is a two-sided hypothesis test because it was unknown before the test whether one or more medians, if significantly different from the others, would be larger or smaller than the others.

For station 08077642, p-values computed for dissolved ammonia nitrogen, total phosphorus, and dissolved orthophosphate are all less than 0.05, indicating that data collected during at least one season are different than the rest (table 11). For station 08077644, only dissolved ammonia nitrogen has a p-value of less than 0.05, indicating some seasonality in this constituent. For station 08077646, p-values computed for total Kjeldahl nitrogen and dissolved orthophosphate are less than 0.05, and for station 08077648, p-values computed for dissolved ammonia nitrogen, total Kjeldahl nitrogen, and total phosphorus are less than 0.05.

For all stations except 08077646 (URBAN), seasonality is indicated for dissolved ammonia nitrogen. This result is consistent with graphs of the time-series data, which show that ammonia concentrations tend to increase in the spring and early summer months. The increases could be related to fertilizer application and washoff; or to processes of decay, stimulated by warm weather, that transform organic nitrogen into ammonia nitrogen. No seasonality is apparent for dissolved nitrite nitrogen, dissolved Kjeldahl nitrogen, and dissolved nitrite plus nitrate nitrogen, indicating that these species are less influenced by cyclical application.

Land Use

Water-quality characteristics of nonpoint-source runoff sometimes can be correlated to land use, as was shown by Baldys and others (1996) for parts of the Dallas-Fort Worth area. For this study, boxplots and hypothesis tests are used to compare nutrient concentrations of storm-event samples collected from watersheds of different land uses. For these comparisons, storm samples collected at the four fixed stations were grouped by the respective land use associated with each station (table 1). Similar water-quality data were obtained from two other USGS stations: 08075770 Hunting Bayou at I–610, Houston, Tex., and 08051500 Clear Creek near Sanger, Tex. (fig. 1). Hunting Bayou drains a predominantly urban watershed of northeast Houston. The Hunting Bayou station is part of the Houston-Urban Runoff Program (HURP) (Liscum and others, 1996) and is located at I–610, which is a major highway that encircles the city of Houston. Clear Creek drains pasture and rangeland approximately 40 mi north of Fort Worth (Van Metre and Reutter, 1995). In this report, Hunting Bayou is designated as HOU–URBAN and Clear Creek is designated as NORTHTEX–PASTURE.

Boxplots show nutrient concentrations associated with the land uses represented by the six stations (fig. 9). For each of the eight selected nutrients, Hunting Bayou (HOU–URBAN) has the largest median concentrations, which indicates that runoff from the extensively urbanized area contains larger concentrations of nutrients than runoff from the less urbanized areas. This result is further substantiated by the fact that, for most nutrients, the smallest median concentrations are for NORTHTEX–PASTURE or PASTURE, which are watersheds of non-urban land use. The boxplots also show that concentrations of the selected nutrients for the four fixed stations in the Dickinson Bayou watershed more closely resemble concentrations of pasture runoff (NORTHTEX–PASTURE) than of an urbanized area (HOU–URBAN).

The Kruskal-Wallis test was used to further investigate whether there are differences in nutrient concentrations that can be attributed to different land uses in the Dickinson Bayou watershed. For the tests, only data collected at the four fixed stations during storm events were used. A level of significance of 0.05 was chosen to test the null hypothesis that the medians of each group are identical. The alternative hypothesis is that at least one of the groups has a different median.

From the test results, the null hypothesis was rejected for dissolved nitrite nitrogen, total Kjeldahl nitrogen, dissolved nitrite plus nitrate nitrogen, dissolved and total phosphorus, and dissolved orthophosphate (table 11). That is, for these six nutrients the median concentration for at least one station differed significantly from the rest. Conversely, the null hypothesis was not rejected for dissolved ammonia nitrogen and dissolved Kjeldahl nitrogen; so the groups were statistically identical at the stations.

The statistical test results are consistent with the boxplots for the four fixed stations shown in figure 9. The boxplots show that the median concentration of dissolved nitrite nitrogen is larger for station URBAN than for the other three stations, and the median concentration of total Kjeldahl nitrogen is larger for station RURAL/RES than for the other three stations. Median concentrations of dissolved nitrite plus nitrate have the largest range; and station URBAN has the largest median. Median concentrations of total and dissolved phosphorus, as well as dissolved orthophosphate, are much smaller at station PASTURE than medians at the other three stations.

Nutrients in Bottom Sediment and Suspended Sediment

Because of the hydrodynamics associated with the slow-moving system, considerable amounts of nutrients can be deposited in the bottom sediment of Dickinson Bayou. Statistically significant spatial trends are not apparent for ammonia nitrogen, Kjeldahl nitrogen, nitrite plus nitrate nitrogen, or phosphorus in bottom sediment; phosphorus concentration does appear to decrease downstream from station 08077640 (fig. 10). The pattern of suspended-sediment concentration is similar to that of phosphorus in bottom sediment, with the largest concentration at station 08077640 and a decreasing trend downstream of station 08077640. Phosphorus tends to attach to suspended sediment, so the similar patterns of the graphs could indicate that stream reaches where sediment settles out of suspension

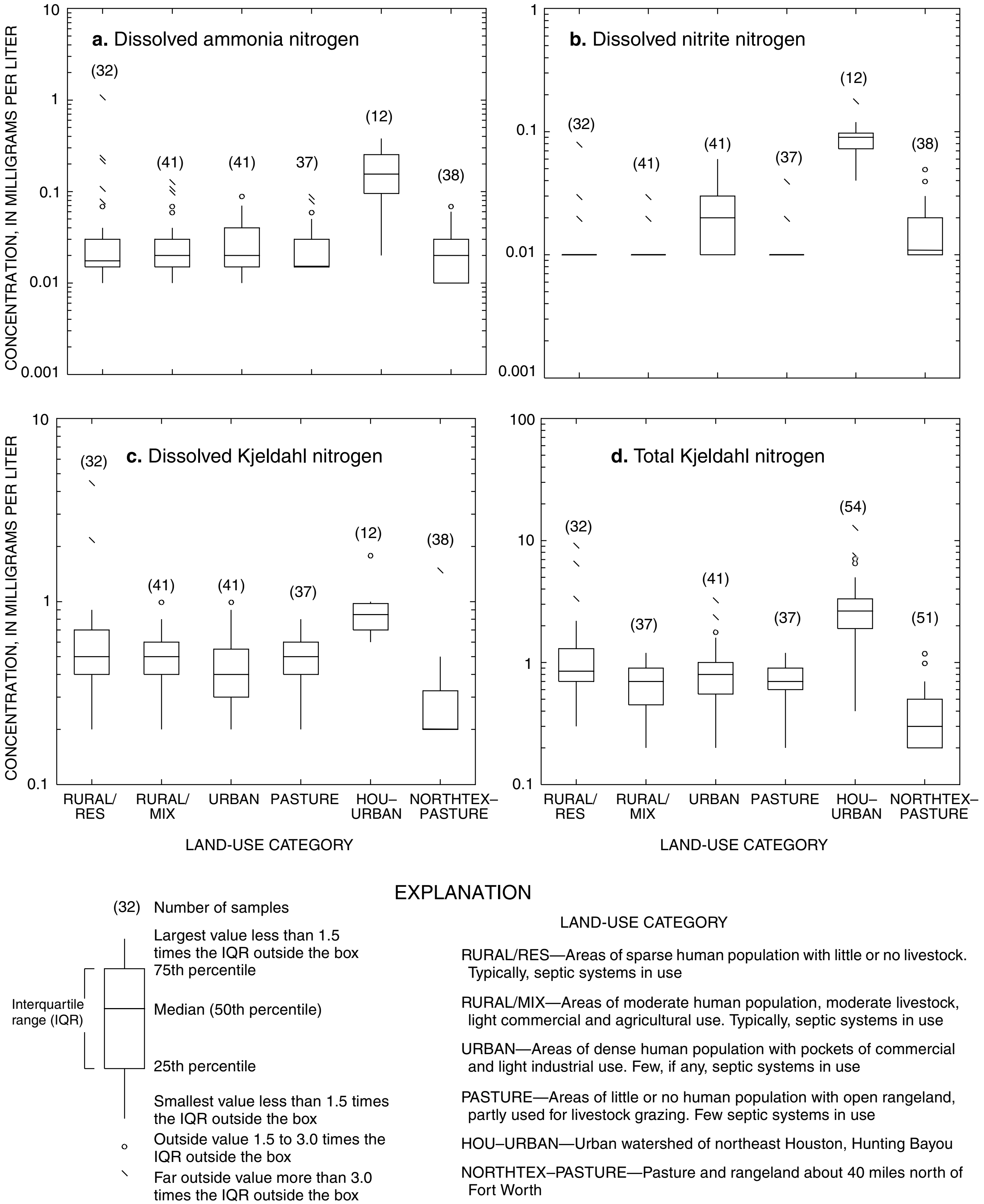

Figure 9. Distributions of concentrations of selected nutrients for land-use categories within and outside Dickinson Bayou watershed near Houston, Texas, 1995–97.

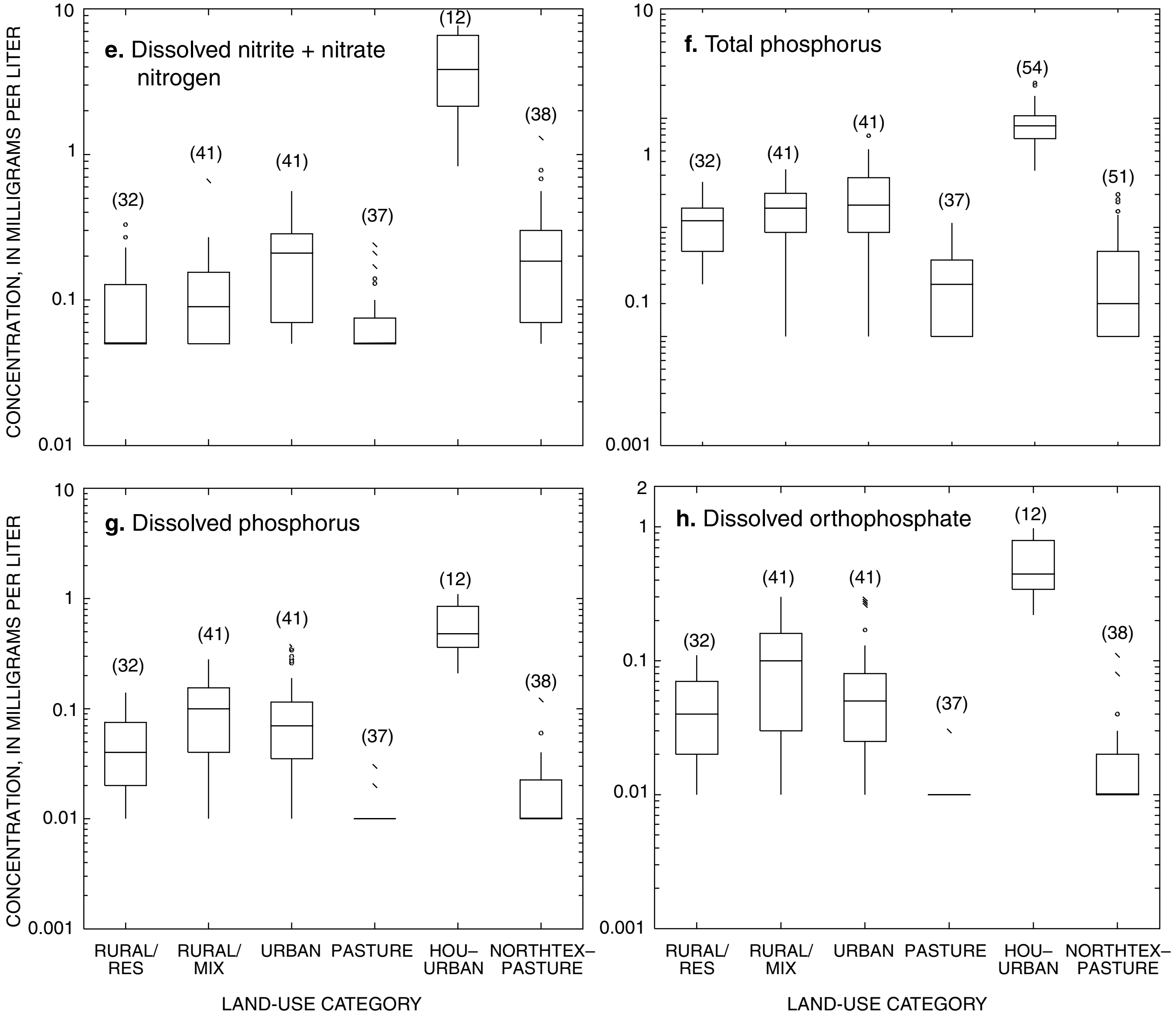

Figure 9.—Continued.

also could be likely sinks for phosphorus in bottom sediment.

BIOLOGICAL CHARACTERISTICS

Periphyton Algal Identification and Enumeration

Periphyton (benthic algae) samples were collected to develop a list of algal taxa present at each station (appendix 1) and to identify nutrient sources (point or nonpoint) inferred from the occurrence and abundance of algal species in the benthic algal community. Many of the algal taxa identified at the six synoptic-survey stations and one fixed station (table 2) have been classified previously as halophilic (tolerance or requirements for waters with high mineral content) and eutrophic (indicative of nutrient-enriched waters) (Prescott, 1962; Lowe, 1974; VanLandingham, 1982). Blue-green algae are predominant at many stations. All algal taxa found during the study are classified alkaliphilic (best development at pH greater than 7 (Lowe, 1974)), which is consistent with pH values measured during the study (from 7.0 to 8.9). Total

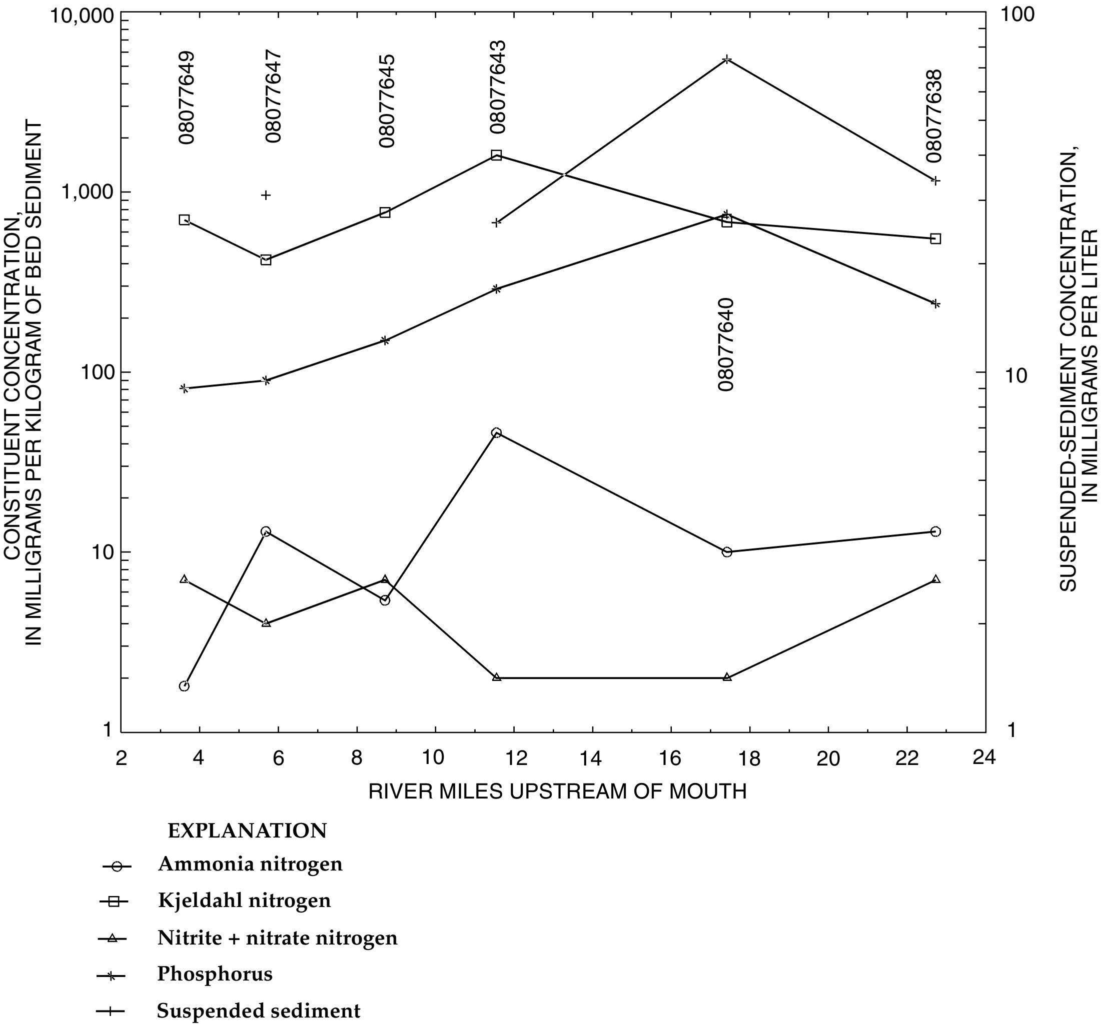

Figure 10. Concentrations of selected nutrients in bottom-sediment samples and of suspended sediment in water samples for selected stations, Dickinson Bayou near Houston, Texas, during low-flow synoptic survey August 22, 1995.

algal cell counts range from 1.1 to 1.9 X 10^6 cells/cm^2 and are relatively similar among the synoptic-survey stations (table 12, at end of report). Secchi-disk depth readings are greater than 36 cm at all stations, indicating that algal colonization and growth on the artificial substrates (tiles) probably is not limited by insufficient light.

The abundance of two functional groups of benthic algae (soil algae and nitrogen-fixing algae) was compared among stations to evaluate sources of nutrients and other water-quality constituents. Predominant soil algae found in Dickinson Bayou include *Schizothrix calcicola* (blue-green algae; Drouet, 1981), *Desmococcus* spp. (green algae; Prescott, 1970), and two diatom species (*Luticola mutica* and *Navicula contenta* var. *biceps*) that are associated with soils or found commonly in streams with large suspended-sediment loads (Lowe, 1974). The relative abundance of soil algae is large (greater than 60 percent) at stations in the middle of the Dickinson Bayou watershed (stations 08077643, 08077644, and 08077647), and moderate (about 50 percent) at stations in the upper part of the watershed (08077638 and 08077640) (table 12).

Algal communities with a large percentage of soil algae are presumed to reflect land disturbances in the basin, such as soil erosion from agricultural areas or

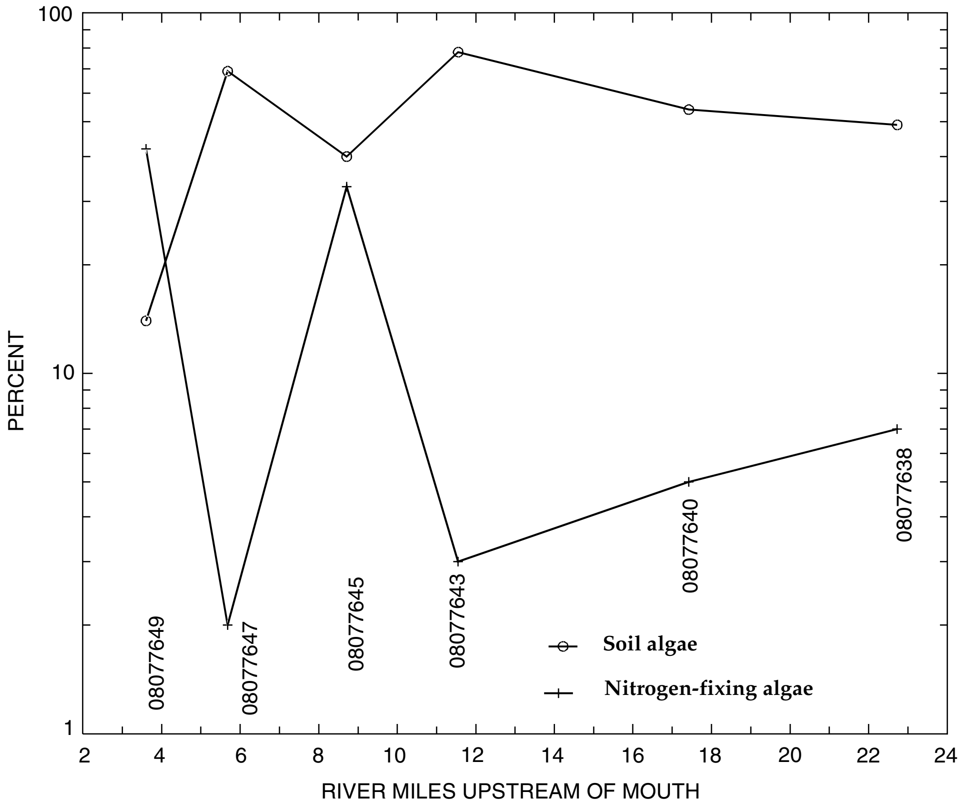

Figure 11. Percentage of soil algae and nitrogen-fixing algae for selected stations, Dickinson Bayou near Houston, Texas, during low-flow synoptic survey August 22, 1995.

construction sites. The large relative abundance of soil algae at stations 08077643 and 08077644 likely indicates cumulative effects from agricultural nonpoint sources, whereas the larger-than-expected abundance of soil algae in the tidal reach of Dickinson Bayou, downstream of three major tributary inflows (Bordens Gully, Magnolia Bayou, and Benson Bayou) (fig. 2; station 08077647) might reflect water-quality influences from predominantly urban nonpoint sources.

The largest abundance (82 percent) of soil algae was found at station 08077644 (Drainage Ditch 9C), a tributary of Dickinson Bayou that receives drainage from agricultural nonpoint sources. Although dissolved nutrient concentrations are small (below reporting limits), algal cell counts are larger than average (table 12), and considerable amounts of benthic algae were observed in the ditch at the time of sample collection. Elevated values for dissolved oxygen (114 percent saturation) and pH (8.7) measured at this station could indicate substantial primary productivity (photosynthesis) was occurring (Warren, 1971, p. 55). Rates of nutrient uptake by the algae could be exceeding nutrient loads, which might explain the small nutrient concentrations detected at this station. No permitted discharges are located on this tributary, so dissolved nutrients in the water would have originated from nonpoint-source runoff.

The relative abundance of soil algae in Dickinson Bayou increases from the most upstream station (08077638) downstream 11 mi to station 08077643 (figs. 2 and 11). The abundance of soil algae then decreases from 78 percent at station 08077643 to 40 percent at station 08077645 (fig. 2; near the I–45 bridge). Downstream of station 08077645 the percentage of soil algae again increases, to 69 percent at station 08077647 near the State Highway 3 bridge approximately 3 mi downstream from the I–45 bridge, and then decreases to 14 percent at the most downstream station (08077649). On the basis of the downstream changes in benthic algal community structure thus described, the authors believe that the effects on water quality of agricultural nonpoint sources in the middle-to-upper parts of the watershed are reduced in the tidal reach near the I–45 bridge station (08077645). However, the increase in the abundance of soil algae in Dickinson Bayou downstream near the State Highway 3 bridge (station 08077647) could be the result of urban nonpoint-source contamination from the three major tributary inflows mentioned previously.

Nitrogen-fixing algae found in Dickinson Bayou include *Anabaina* and *Calothrix* (blue-green algae; Drouet, 1981), as well as certain diatoms known to contain blue-green algae (for example, *Rhopalodia* spp.; Geitler, 1977; Fairchild and Lowe, 1984). Nitrogen-fixing algae have a competitive advantage in eutrophic waters that are rich in phosphorus but contain relatively little nitrogen because they can use dissolved nitrogen gas in the water as an available source of nitrogen (Bold and Wynne, 1978). Thus, the abundance of nitrogen-fixing algae can be relatively large at stations where concentrations of nitrogen in the water are small but other algal-growth factors (for example, phosphorus and light) are available in sufficient supply (Cuffney and others, 1997).

The abundance of nitrogen-fixing algae generally is larger in the tidal reach of Dickinson Bayou than in the non-tidal reach upstream of station 08077643 (approximately mid-basin), possibly indicating that seasonal depletion of nitrogen in the tidal reach could limit algal production in the tidal reach of Dickinson Bayou. Figure 8b indicates that nitrogen concentrations are relatively smaller at the tidal-reach stations (08077645, 08077647, and 08077649), and that nitrogen/phosphorus relations differ between the tidal and above-tidal reaches of the bayou. For example, compared with stations in the above-tidal reach (08077638, 08077640, and 08077643), the tidal-reach stations have relatively smaller concentrations of dissolved nitrite plus nitrate nitrogen and relatively larger concentrations of dissolved orthophosphate. Although nutrient concentrations do not appear to limit algal production in the upper (above-tidal) reach of Dickinson Bayou, the relatively smaller nitrogen concentrations, increased abundance of nitrogen-fixing algae, and relatively larger concentrations of dissolved orthophosphate at the tidal-reach stations might indicate that depletion of nitrogen in the water column was limiting benthic-algal production in the lower (tidal) reach of the bayou during the synoptic survey. If nitrogen is the limiting resource for algal productivity in Dickinson Bayou, eutrophication of the system could be (at least partially) mitigated if nonpoint-source nutrient loads into the Bayou were reduced.

The smaller-than-expected abundance of nitrogen-fixing algae at station 08077647 (State Highway 3 bridge; fig. 2) corresponds negatively with the larger-than-expected abundance of soil algae at this tidal-reach station (fig. 11; table 12). As discussed previously, the authors believe that tributary nonpoint-source loading from mixed urban/agricultural sources in the Bordens Gully, Magnolia Bayou, and Benson Bayou drainage basins is influencing water-quality conditions in the reach of Dickinson Bayou near station 08077647. Increases in nitrogen loads at station 08077647 (relative to station 08077645, 3 mi upstream) (fig. 9) could mean that nutrients (notably nitrogen) do not limit algal production in this reach of the bayou, a selective disadvantage for nitrogen-fixing algae that are successful competitors with other eutrophic algae only when concentrations of dissolved nitrite plus nitrate nitrogen are small or not detected in water samples.

Chlorophyll

Chlorophyll *a* and *b* are photosynthetic pigments of algae (and other green plants) used to produce energy from light. The relative concentration of chlorophyll *a* often has been used to estimate the amount of phytoplankton or periphyton in a waterbody (Porter and others, 1993). All algae contain chlorophyll *a*; however, the only algal taxa found in Dickinson Bayou that contain chlorophyll *b* are green algae (for example, *Desmococcus*, *Chaetophora*, *Scenedesmus*, and *Chlamydomonas*; refer to appendix 1). Ratios of chlorophyll *a* to chlorophyll *b* (CHL*a*/CHL*b*) were computed to evaluate relative contributions of major algal divisions (for example, green algae, blue-green algae, and diatoms) to the benthic-algal community. Low CHL*a*/CHL*b* ratios indicate relatively greater dominance of (photosynthetically active) green algae, whereas high CHL*a*/CHL*b* ratios indicate dominance of blue-green algae and diatoms. Chlorophyll data collected from Dickinson Bayou during the low-flow synoptic survey are shown in figure 12 and listed in table 12.

Periphyton chlorophyll *a* concentrations are relatively larger at stations in the above-tidal reach of Dickinson Bayou, particularly in relation to algal cell counts (table 12). With one exception, chlorophyll *a* concentrations decrease from the most upstream station (08077638) to the two most downstream stations in the

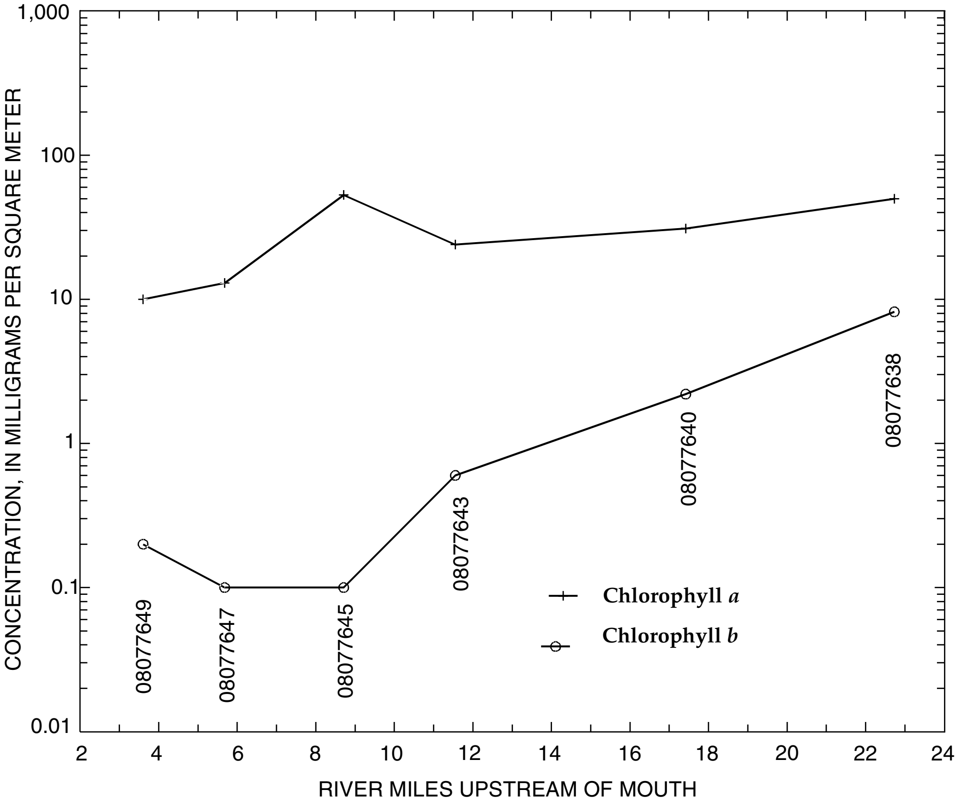

Figure 12. Concentrations of chlorophyll *a* and chlorophyll *b* for selected stations, Dickinson Bayou near Houston, Texas, during low-flow synoptic survey August 22, 1995.

tidal reach (08077647 and 08077649) (fig. 12). Chlorophyll *a* concentrations are largest at station 08077638 (above-tidal reach station below City of Friendswood wastewater-treatment plant) and station 08077645 (tidal-reach station near I–45 bridge; fig. 2). Algal cell counts at those stations were among the largest during the study (table 12).

Chlorophyll *b* concentrations also decrease from upstream to downstream (fig. 12); however, concentrations are relatively larger at stations proximate to point-source discharges (station 08077638) or agricultural nonpoint sources (stations 08077640 and 08077644) of nutrient enrichment (table 12). CHL*a*/CHL*b* ratios are less than 20 at those three stations, indicating that a greater percentage of green algae was photosynthetically active at the time of the study. In contrast, CHL*a*/CHL*b* ratios are generally greater than 50 at stations in the tidal reach, indicating relatively smaller percentages of green algae and greater abundance of blue-green algae and diatoms. Analyses of algal community structure confirm the predictions of the CHL*a*/CHL*b* ratios. Green algal taxa such as *Desmococcus*, *Cladophora*, and *Chaetophora* are relatively more abundant at stations with small drainage basins (for example, 08077638, 08077640, and 08077644; table 1) near nutrient sources in the above-tidal reach than at stations in the tidal reach of Dickinson Bayou that integrate water-quality conditions over considerably larger drainage areas.

Although the chlorophyll *a* concentration (as well as the algal cell count) at station 08077645 (tidal reach near I–45 bridge) is among the highest measured in the study (table 12), the chlorophyll *b* concentration is less than the analytical reporting limit (0.1 mg/m^2), resulting in the largest CHL*a*/CHL*b* ratio. Examination of algal community structure at this station indicates a co-dominance of soil algae and nitrogen-fixing algae (table 12; appendix 1). When compared with station 08077643, 3 mi upstream from station 08077645, algal and nutrient relations differ considerably. For example, concentrations and loads of dissolved orthophosphate and ammonia nitrogen are more than four times larger than those at the upstream station (fig. 5a, b). Tributary inflow from Runge Bayou and associated drainage ditches upstream from station 08077645 (fig. 2) might be influencing water quality by increasing loads of nitrogen and phosphorus that stimulate algal production in Dickinson Bayou. Sources of nutrients in Runge Bayou primarily are agricultural.

SUMMARY

Excessive nutrient levels in waterbodies can cause prolific algal growth and eutrophication, resulting in decomposition of plant and organic matter, increased oxygen demand, and fish kills. Nutrient loads can be traced to atmospheric deposition (rainfall), point sources (for example, wastewater discharges), and nonpoint sources (stormwater runoff and ground-water discharge). In this report, the concentrations, loads, and yields of selected nutrients that enter Dickinson Bayou from point and nonpoint sources were estimated; and the effects on nutrient concentrations of flow conditions, seasonality, and land use were characterized during a 2-year study (March 1995–February 1997). Also, the effects that nutrient loads have had on selected biological characteristics (algae and chlorophyll) were evaluated.

Data collected include rainfall, streamflow, stream water quality (sediment, nutrient, and biological), as well as QA/QC samples to ensure the adequacy of the methods used for data collection and data analysis. Water-quality samples were collected monthly during low-flow conditions and during high-flow (storm-event) conditions. Data were collected at 10 USGS stations during the study: 4 fixed stations, each with a drainage basin of different primary land use, and 6 synoptic stations along the mainstem of Dickinson Bayou.

A low-flow synoptic survey was done to provide a “snapshot” of water-quality conditions along the bayou during low-flow conditions. Data collected during the low-flow survey show that, while concentrations of most of the dissolved nutrients tend to decrease in a downstream direction, nutrient loads increase. Larger downstream loads primarily are caused by increased streamflow in the tidal reach of the bayou. During the survey, one constituent concentration exceeded the TNRCC screening level of 1.0 mg/L: The concentration of dissolved nitrite plus nitrate nitrogen for station 08077638 is 2.40 mg/L. Also during the low-flow survey, dissolved oxygen concentrations in the non-tidal reach of the bayou (characterized by shallow, flowing waters) were larger than dissolved oxygen concentrations in the tidal reach (characterized by deep, sluggish waters). These results are in agreement with previous studies, which have shown small dissolved oxygen concentrations in the tidal reach of Dickinson Bayou.

A high-flow synoptic survey provided a measure of nutrient loads in the bayou during and after a storm event, when nonpoint-source loads are predominant. These data show that nutrient loads are larger during storm events than during low-flow conditions. Estimated nonpoint-source loads from storm runoff for a 3-day period are at least twice the estimated point-source loads for the same 3-day period. Also, nutrient loads increase at downstream stations as a result of increased storm runoff.

Estimates of loads of selected nutrients for the 106-mi^2 watershed during the study were made for point and nonpoint sources. Estimates of rainfall-deposition rates of selected nutrients during the same period also were made to allow comparison with point- and nonpoint-source loads. Rainfall-deposition rates are estimated to be 110 lb/d of dissolved ammonia nitrogen, 120 lb/d of dissolved nitrate nitrogen, and 15.8 lb/d of dissolved phosphorus. Point-source loading data are available only for ammonia nitrogen. Approximately 21.3 lb/d of ammonia nitrogen is estimated from point sources during the study period. Nonpoint-source loads are estimated for eight nutrient species: 7.84 lb/d of dissolved ammonia nitrogen, 5.79 lb/d of dissolved nitrite nitrogen, 215 lb/d of dissolved Kjeldahl nitrogen, 350 lb/d of total Kjeldahl nitrogen, 40.1 lb/d of dissolved nitrite plus nitrate nitrogen, 67.6 lb/d of total phosphorus, 46.6 lb/d of dissolved phosphorus, and 42.8 lb/d of dissolved orthophosphate.

Three parameters are used as indicators of the water quality of the bayou: BOD, fecal coliform bacteria, and toxicity. BOD is an empirical value used to express stream-pollution loads. Fecal coliform bacteria are used as indicators of possible contamination from feces of humans or other warm-blooded animals. Toxicity is an empirical measure of the morbidity rate of aquatic life in a water sample. BOD analyses for samples collected during low-flow conditions range from 1 to 5 mg/L and for samples collected during storm events range from 3 to 10 mg/L. Fecal coliform bacteria increases appreciably during storm events. Measurable toxicity was reported for only one of the samples analyzed by a microtox instrument; measurable toxicity was not reported for samples subjected to USEPA biomonitoring analysis.

Statistical tests were used to determine whether there are significant differences between nutrient concentrations during low-flow and during high-flow conditions. For basins with rural/mixed and urban land uses, nutrient concentrations generally are significantly greater during storm events than during low flow, indicating accumulation of nutrients in the watershed and subsequent washoff. However, nutrient concentrations in storm-event samples from sites that predominantly drain pasture land generally are not significantly greater than those in low-flow samples. Statistical tests for seasonality indicate that dissolved ammonia nitrogen is significantly different in at least one season for all land uses except urban. Concentrations tend to increase in the spring and early summer, possibly from fertilizer application and subsequent washoff.

Constituent-yield data were used to make direct comparisons of the nonpoint-source load contributions from four stations with watersheds of different land use. These comparisons lead to three conclusions: (1) For all nutrient species except orthophosphate, urban land use is the largest nonpoint-source contributor, (2) Kjeldahl nitrogen is the most abundant nutrient species, and (3) organic nitrogen accounts for the major part of the Kjeldahl nitrogen.

Comparison of nutrient concentration data with similar information from two additional USGS stations outside the Dickinson Bayou watershed shows that runoff from an extensively urbanized area contains larger concentrations of nutrients than runoff from less urbanized areas.

Benthic algae samples were collected at six synoptic stations and one fixed station and were analyzed for periphyton ID/enumeration and for chlorophyll *a* and chlorophyll *b* concentrations. The abundance of two functional groups of algae (soil algae and nitrogen-fixing algae) was compared among stations, primarily to identify the sources of nutrients (point or nonpoint) in the Dickinson Bayou watershed.

Algal communities with a large percentage of soil algae are presumed to reflect land disturbances in the basin, such as soil erosion from agricultural areas or construction sites. The large relative abundance of soil algae at stations in the middle of the watershed likely indicates the cumulative effects on water quality of agricultural nonpoint sources. A decrease in relative abundance of soil algae in the tidal reach near the I–45 bridge probably indicates that the effects on water quality of agricultural nonpoint sources in the middle-to-upper parts of the watershed are reduced near the I–45 bridge. Farther downstream near the State Highway 3 bridge, and downstream of three major tributary inflows, the increase in abundance of soil algae to a larger-than-expected level might reflect water-quality influences from predominantly urban nonpoint sources in the drainage basins of the three major tributary inflows.

The abundance of nitrogen-fixing algae generally is larger in the tidal reach of Dickinson Bayou than in the non-tidal reach, possibly indicating that seasonal depletion of nitrogen in the tidal reach could limit algal production in the tidal reach. Nutrient concentrations do not appear to limit algal production in the upper (non-tidal) reach of Dickinson Bayou; but the relatively smaller nitrogen concentrations, increased abundance of nitrogen-fixing algae, and relatively larger concentrations of dissolved orthophosphate at the tidal-reach stations might indicate that depletion of nitrogen in the water column was limiting benthic-algal production in the lower (tidal) reach of the bayou during the time of the synoptic survey. If nitrogen is the limiting resource for algal productivity in the tidal reach of Dickinson Bayou, eutrophication of the system could be (at least partially) mitigated if nonpoint-source nutrient loads into the Bayou were reduced.

Periphyton chlorophyll *a* concentrations are relatively larger at stations in the non-tidal reach of Dickinson Bayou, particularly in relation to algal cell counts. Chlorophyll *b* concentrations also decrease from upstream to downstream; however, concentrations are relatively larger at stations proximate to point-source discharges or agricultural nonpoint sources of nutrient enrichment. CHL*a*/CHL*b* ratios are less than 20 at those stations, indicating that a greater percentage of green algae was photosynthetically active at the time of the study. In contrast, CHL*a*/CHL*b* ratios are generally greater than 50 at stations in the tidal reach, indicating relatively smaller percentages of green algae and greater abundance of blue-green algae and diatoms. Green algal taxa are relatively more abundant at stations with small drainage basins near nutrient sources in the non-tidal reach than at stations in the tidal reach of Dickinson Bayou that integrate water-quality conditions over considerably larger drainage areas.

SELECTED REFERENCES

Baldys, Stanley, III, Raines, T.H., Mansfield, B.L., and Sandlin, J.T., 1996, Hydrologic data for urban stormwater studies in the Dallas-Fort Worth area, Texas, 1992–94: U.S. Geological Survey Open-File Report 96–482, 254 p.

Bold, H.C., and Wynne, M.J., 1978, Introduction to the algae—Structure and reproduction: Englewood Cliffs, N.J., Prentice-Hall, Inc., p. 31–62.

Cuffney, T.F., Meador, M.R., Porter, S.D., and Gurtz, M.E., 1997, Distribution of fish, benthic invertebrate, and algal communities in relation to physical and chemical conditions, Yakima River Basin, Washington, 1990: U.S. Geological Survey Water-Resources Investigations Report 96–4280, 94 p.

Drouet, F., 1981, Revision of the *Stigonemataceae* with a summary of the classification of the blue-green algae: Vaduz, Germany, J. Cramer Publishers, Beihefte zur Nova Hedwigia, v. 66, p. 161–166.

Dunn, D.D., 1996, Trends in nutrient inflows to the Gulf of Mexico from streams draining the conterminous United States, 1972–93: U.S. Geological Survey Water-Resources Investigations Report 96–4113, 60 p.

Fairchild, G.W., and Lowe, R.L., 1984, Artificial substrates which release nutrients—Effects on periphyton and invertebrate succession: Hydrobiologia, v. 114, p. 29–37.

Geitler, L., 1977, Zur Entwicklungsgeschichte der Epithemiaceen Epithemia, Rhopalodia, und Denticula (Diatomophyceae) und ihre vermutlich symbiotischen Spharoidkorper: Pl. Syst. Evolution, v. 128, p. 259–275.

Helsel, D.R., and Hirsch, R.M., 1992, Studies in environmental science 49–Statistical methods in water resources: Amsterdam, Elsevier, 522 p.

Hem, J.D., 1992, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hershfield, D.M., 1961, Rainfall frequency atlas for the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years: U.S. Weather Bureau Technical Paper 40, 7 p., 54 charts.

Kirkpatrick, Jeff, 1986a, Intensive survey of Dickinson Bayou tidal, segment 1103, November 27–29, 1984: Texas Water Commission, IS 86–03, 26 p.

______1986b, Intensive survey of Dickinson Bayou above tidal, segment 1104, May 6–7, 1985: Texas Water Commission, IS 86–07, 21 p.

Koltun, G.F., Gray, J.R., and McElhone, T.J., 1994, Users manual for SEDCALC, a computer program for computation of suspended-sediment discharge: U.S. Geological Survey Open File Report 94–459, 46 p.

Liscum, Fred, Brown, D.W., and Kasmarek, M.C., 1996, Summary of surface-water hydrologic data for the Houston metropolitan area, Texas, water years 1964–89: U.S. Geological Survey Open-File Report 96–250, 44 p.

Lowe, R.L., 1974, Environmental requirements and pollution tolerance of freshwater diatoms: U.S. Environmental Protection Agency, National Environmental Research Center, Office of Research and Development, EPA 670/4–74–005, 334 p.

Microbics Corp., 1992, Microtox manual—v. 4. Data quality and applying results: p. 401–472.

National Weather Service, 1997, Climatological data: Department of Commerce, National Oceanic and Atmospheric Administration. URL: *http://www.srh.noaa.gov/FTPROOT/HGX/HTML/index3/climate3.htm*

Plafkin, J.L, Barbour, M.T., Porter, K.D., Gross, S.K., and Hughes, R.M., 1989, Rapid assessment protocols for use in streams and rivers—Benthic macroinvertebrates and fish: Washington, D.C., U.S. Environmental Protection Agency.

Porter, S.D., Cuffney, T.F., Gurtz, M.E., and Meador, M.R., 1993, Methods for collecting algal samples as part of the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 93–409, 39 p.

Prescott, G.W., 1962, Algae of the western Great Lakes area: Dubuque, Iowa, William C. Brown Publishers, 977 p.

______1970, How to know the freshwater algae: Dubuque, Iowa, William C. Brown Publishers, 70 p.

Rantz and others, 1982, Measurement and computation of streamflow—v. 2. Computation of discharge: U.S. Geological Survey Water-Supply Paper 2175, p. 285–631.

Terrio, P.J., 1995, Water-quality assessment of the Upper Illinois River Basin in Illinois, Indiana, and Wisconsin—Nutrients, dissolved oxygen, and fecal-indicator bacteria in surface water, April 1987 through August 1990: U.S. Geological Survey Water-Resources Investigations Report 95–4005, 79 p.

Texas Natural Resource Conservation Commission, 1996, The State of Texas water quality inventory (13th ed.): Austin, Tex., v. 1, SFR–50, 655 p.

Texas Water Commission, 1992, The State of Texas water quality inventory (11th ed.): Austin, Tex., LP 92–16, 671 p.

U.S. Environmental Protection Agency, 1986, Quality criteria for water, 1986: Washington, D.C., U.S. Environmental Protection Agency Report EPA 440/5–86–001 [variously paged].

U.S. Geological Survey, 1990, Land use and land cover digital data from 1:250,000- and 1:100,000-scale maps: U.S. Geodata Users Guide 4, 33 p.

VanLandingham. S.L., 1982, Guide to the identification, environmental requirements and pollution tolerance of freshwater blue-green algae (*Cyanophyta*): U.S. Environmental Protection Agency, National Environmental Research Center, Office of Research and Development, EPA–600/3–82–073, 341 p.

Van Metre, P.C., and Reutter, D.C., 1995, Water-quality assessment of the Trinity River Basin, Texas—Analysis of available information on nutrients and suspended sediments, 1974–91: U.S. Geological Survey Water-Resources Investigations Report 94–4086, 71 p.

Viessman, Warren, and Hammer, M.J., 1985, Water supply and pollution control (4th ed.): New York, Harper & Row, 797 p.

Warren, C.E., 1971, Biology and water pollution control: W.B. Saunders Co., 434 p.

Wells, F.C., Gibbons, W.J., and Dorsey, M.E., 1990, Guidelines for collection and field analysis of water-quality samples from streams in Texas: U.S. Geological Survey Open-File Report 90–127, 79 p.

Table 1. Selected characteristics of data-collection sites, Dickinson Bayou near Houston, Texas, 1995–97

[mi^2, square miles; mi, miles; na, not available; RURAL/RES, rural/residential; RURAL/MIX, rural/mixed]

Station number (fig. 2)	Station name	Drainage area (mi^2)	Distance upstream from mouth of Dickinson Bay (mi)	Predominant land use
	Fixed stations			
08077642	Drainage ditch at Leisure Ln. near Alvin, Tex.[1]	0.69	na	RURAL/RES
08077644	Drainage Ditch 9C at Fourth St. near Santa Fe, Tex.	2.32	na	RURAL/MIX
08077646	Central St. Drainage Ditch at Dickinson, Tex.	.40	na	URBAN
08077648	Gum Bayou at Farm Road 1266 near League City, Tex.	1.40	na	PASTURE
	Synoptic stations			
08077638	Dickinson Bayou at Farm Road 528 near Alvin, Tex.	1.17	22.7	na
08077640	Dickinson Bayou at Farm Road 517 near Alvin, Tex.	na	17.4	na
08077643	Dickinson Bayou at Cemetary Rd. near Santa Fe, Tex.	na	11.6	na
08077645	Dickinson Bayou at I–45 at Dickinson, Tex.	na	8.71	na
08077647	Dickinson Bayou at State Highway 3, Dickinson, Tex.	75.6	5.68	na
08077649	Gum Bayou at Farm Road 517 near Texas City, Tex.	na	3.60	na

[1] This drainage ditch has no official name. In this report it is referred to as drainage ditch at Leisure Ln.

Table 2. Summary of sampling activities, Dickinson Bayou near Houston, Texas, 1995–97

Type of station and number	Monthly sampling (each of 12 months during March 1995–February 1997)
Fixed	**Streamflow; properties and constituents**
08077642	Continuous streamflow
08077644	Temperature
08077646	Specific conductance
08077648	pH
	Dissolved oxygen
	Alkalinity
	Biochemical oxygen demand
	Fecal coliform bacteria
	Toxicity
Water-quality suite	Dissolved ammonia nitrogen
	Dissolved nitrite nitrogen
	Dissolved Kjeldahl nitrogen
	Total Kjeldahl nitrogen
	Dissolved nitrite plus nitrate nitrogen
	Total phosphorus
	Dissolved phosphorus
	Dissolved orthophosphate
	Suspended sediment

Table 2. Summary of sampling activities, Dickinson Bayou near Houston, Texas, 1995–97—Continued

Type of station and number	Storm-event sampling (8 storm events during March 1995–February 1997
Fixed	**Properties and constituents**
08077642	Water-quality suite
08077644	
08077646	
08077648	

Type of station and number	Low-flow synoptic sampling (August 22, 1995)
Synoptic	**Streamflow; properties and constituents**
08077638	Instantaneous streamflow
08077640	Water-quality suite (also includes toxicity expressed as percent organisms affected)
08077643	**Bottom sediment**
08077645	Ammonia nitrogen
08077647	Kjeldahl nitrogen
08077649	Nitrite plus nitrate nitrogen
Fixed	Phosphorus
08077644	**Algae**
(no bottom-sediment samples)	Periphyton algal ID/enumeration
08077646 (no bottom-sediment samples; no algal samples)	Chlorophyll *a*, *b*

Type of station and number	High-flow synoptic sampling (January 27–29, 1997)
Synoptic	**Streamflow; properties and constituents**
08077638	Instantaneous streamflow
08077647	Water-quality suite
Fixed	
08077642	
08077644	
08077646	
08077648	

Type of station and number	Miscellaneous rainfall sampling (June 1995 and June 1996)
Fixed	Dissolved ammonia nitrogen
08077646	Dissolved nitrite nitrogen
	Dissolved Kjeldahl nitrogen
	Total Kjeldahl nitrogen
	Dissolved nitrite plus nitrate nitrogen
	Total phosphorus
	Dissolved phosphorus
	Dissolved orthophosphate

Table 2. Summary of sampling activities, Dickinson Bayou near Houston, Texas, 1995–97—Continued

Quality-assurance/quality-control sampling
15 equipment blanks
7 field blanks
10 sets split samples
10 concurrent samples
25 sets spike samples
1 algal sample

Table 3. Concentrations of selected nutrients in rainfall samples collected in the Dickinson Bayou watershed (station 08077646 Central Street Drainage Ditch at Dickinson, Tex.) and at the Attwater Prairie Chicken National Wildlife Refuge near Sealy, Texas, June 1995 and June 1996

[All concentrations are in milligrams per liter. <, less than; na, not available]

Constituent	Concentration June 30, 1995		Concentration June 23, 1996	
	Dickinson Bayou watershed	Attwater Prairie Chicken	Dickinson Bayou watershed	Attwater Prairie Chicken
Dissolved ammonia nitrogen	0.060	0.11	0.080	0.07
Dissolved nitrite nitrogen	<.010	na	<.010	na
Dissolved nitrate nitrogen	.10	.64	<.05	.32
Dissolved Kjeldahl nitrogen	<.20	na	<.20	na
Total Kjeldahl nitrogen	.50	na	<.20	na
Total phosphorus	.02	na	.01	na
Dissolved phosphorus	.01	<.003	.01	na
Dissolved orthophosphate	<.01	na	<.01	na

Table 4. Permitted discharges in the Dickinson Bayou watershed near Houston, Texas, 1995–97

[TNRCC, Texas Natural Resource Conservation Commission; Mgal/d, million gallons per day; na, not available]

TNRCC permit number[1]	Map reference number (fig. 2)	Name of permittee	TNRCC stream segment number[2]	Permit type	Permitted flow (Mgal/d)[3]
10175 - 003	PS1	City of Friendswood - Towers Estate Plant	1104	Treated wastewater	0.40
03416 - 000	PS2	Waste Management of Texas, Inc.	1104	Treated stormwater	na
03474 - 000	PS3	Chemical Distributors, Inc.	1104	Treated stormwater	.0019
00377 - 00	PS4	Pennzoil Products Co. - Penreco	1103	Treated wastewater	.075
02851 - 000	PS5	Torque Petroleum Products, Inc.	1103	Stormwater	na
10568 - 007	PS6	City of League City - Bayridge Wastewater Treatment Facility	1103	Treated wastewater	.15
10173 - 001	PS7	Galveston County Water Control & Improvement District No. 1 - Plant No. 1	1103	Treated wastewater	3.6
10173 - 002	PS8	Galveston County Water Control & Improvement District No. 1 - Plant No. 2	1103	Treated wastewater	.5

[1] Texas Natural Resource Conservation Commission, written commun., 1997.

[2] Segment 1104 is Dickinson Bayou above-tidal reach. Segment 1103 is Dickinson Bayou tidal reach.

[3] Galveston County Health District, written commun., 1997.

Table 5. Summary statistics of monthly streamflow and water-quality data for fixed stations, Dickinson Bayou near Houston, Texas, March 1995–February 1997

[ft^3/s, cubic feet per second; na, not applicable; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; cols./100 mL, colonies per 100 milliliters; TU, U.S. Environmental Protection Agency toxicity units; <, less than]

Property or constituent (unit of measure)	Number of samples	Value	Standard deviation	Minimum value	Maximum value	Minimum reporting level	Number below reporting level
08077642 Drainage ditch at Leisure Ln. near Alvin, Tex.							
Instantaneous streamflow (ft^3/s)	1	2.20	na	na	na	na	na
Temperature (°C)	1	15.0	na	na	na	na	na
Specific conductance (µS/cm)	1	296	na	na	na	na	na
pH (standard units)	1	7.6	na	na	na	na	na
Dissolved oxygen (mg/L)	1	7.8	na	na	na	na	na
Alkalinity (mg/L as $CaCO_3$)	1	101	na	na	na	na	na
5-day biochemical oxygen demand^2 (mg/L)	0	na	na	na	na	na	na
Fecal coliform bacteria^2 (cols./100 mL)	1	1,300	na	na	na	20	na
Toxicity (TU)^3	1	1.76	na	na	na	na	na
Dissolved ammonia nitrogen (mg/L)	1	<.015	na	na	na	.015	1
Dissolved nitrite nitrogen (mg/L)	1	<.01	na	na	na	.01	1
Dissolved Kjeldahl nitrogen (mg/L)	1	.60	na	na	na	.20	0
Total Kjeldahl nitrogen (mg/L)	1	1.1	na	na	na	.20	0
Dissolved nitrite plus nitrate nitrogen (mg/L)	1	<.050	na	na	na	.050	1
Total phosphorus (mg/L)	1	.100	na	na	na	.010	0
Dissolved phosphorus (mg/L)	1	.020	na	na	na	.010	0
Dissolved orthophosphate (mg/L)	1	<.010	na	na	na	.010	1
Suspended sediment (mg/L)	1	143	na	na	na	na	na

Footnotes at end of table.

Table 5. Summary statistics of monthly streamflow and water-quality data for fixed stations, Dickinson Bayou near Houston, Texas, March 1995–February 1997—Continued

Property or constituent	Number of samples	Median value	Mean value[1]	Standard deviation[1]	Minimum value	Maximum value	Minimum reporting level	Number below reporting level
08077644 Drainage Ditch 9C at Fourth St. near Santa Fe, Tex.								
Instantaneous streamflow (ft^3/s)	9	0.18	0.37	0.61	0.01	1.93	na	na
Temperature (°C)	9	23.0	22.4	5.2	15.0	29.5	na	na
Specific conductance (µS/cm)	9	784	790	124	565	917	na	na
pH (standard units)	9	7.8	7.7	.3	7.0	8.2	na	na
Dissolved oxygen (mg/L)	9	7.0	6.3	1.8	4.0	8.7	na	na
Alkalinity (mg/L as $CaCO_3$)	9	310	299	65.3	198	380	na	na
5-day biochemical oxygen demand[2] (mg/L)	5	1	1.2	.4	1	2	na	na
Fecal coliform bacteria[2] (cols./100 mL)	7	300	570	614	<20	1,700	20	1
Toxicity[3] (TU)	9	0	0	na	na	na	na	na
Dissolved ammonia nitrogen (mg/L)	9	<.015	.017	.016	<.015	.060	.015	7
Dissolved nitrite nitrogen (mg/L)	9	<.01	.01	0	<.01	.01	.01	8
Dissolved Kjeldahl nitrogen (mg/L)	9	.30	.40	.26	<.20	1.0	.20	2
Total Kjeldahl nitrogen (mg/L)	9	.30	.36	.18	<.20	.80	.20	2
Dissolved nitrite plus nitrate nitrogen (mg/L)	9	<.050	.050	0	<.050	<.050	.050	9
Total phosphorus (mg/L)	9	.030	.040	.040	<.010	.140	.010	3
Dissolved phosphorus (mg/L)	9	<.010	.022	.029	<.010	.100	.010	5
Dissolved orthophosphate (mg/L)	9	<.010	.018	.020	<.010	.070	.010	6
Suspended sediment (mg/L)	5	42.0	52.6	39.6	16.0	117	na	na

Footnotes at end of table.

Table 5. Summary statistics of monthly streamflow and water-quality data for fixed stations, Dickinson Bayou near Houston, Texas, March 1995–February 1997—Continued

Property or constituent	Number of samples	Median value	Mean value[1]	Standard deviation[1]	Minimum value	Maximum value	Minimum reporting level	Number below reporting level
08077646 Central St. Drainage Ditch at Dickinson, Tex.								
Instantaneous streamflow (ft^3/s)	9	0.01	0.02	0.01	0.01	0.05	na	na
Temperature (°C)	9	23.0	23.5	5.6	17.0	32.0	na	na
Specific conductance (µS/cm)	9	1,080	1,034	282	653	1,360	na	na
pH (standard units)	9	8.1	8.2	.3	7.8	8.7	na	na
Dissolved oxygen (mg/L)	9	5.8	6.9	2.7	4.0	12.0	na	na
Alkalinity (mg/L as $CaCO_3$)	9	320	315	78.0	198	410	na	na
5-day biochemical oxygen demand[2] (mg/L)	5	3	3.2	.5	2	5	na	na
Fecal coliform bacteria[2] (cols./100 mL)	7	800	1,540	1,210	270	3,000	20	0
Toxicity[3] (TU)	9	0	0	na	na	na	na	na
Dissolved ammonia nitrogen (mg/L)	9	<.015	.018	.011	<.015	.040	.015	5
Dissolved nitrite nitrogen (mg/L)	9	<.01	.01	.01	<.01	.03	.01	7
Dissolved Kjeldahl nitrogen (mg/L)	9	.30	.36	.16	<.20	.70	.20	2
Total Kjeldahl nitrogen (mg/L)	9	.50	.52	.25	<.20	.90	.20	2
Dissolved nitrite plus nitrate nitrogen (mg/L)	9	<.050	.052	.01	<.050	.070	.050	8
Total phosphorus (mg/L)	9	.060	.051	.025	<.010	.080	.010	1
Dissolved phosphorus (mg/L)	9	.010	.017	.011	<.010	.040	.010	3
Dissolved orthophosphate (mg/L)	9	<.010	.012	.007	<.010	.030	.010	6
Suspended sediment (mg/L)	8	70.0	82.8	44.5	29.0	164	na	na

Footnotes at end of table.

Table 5. Summary statistics of monthly streamflow and water-quality data for fixed stations, Dickinson Bayou near Houston, Texas, March 1995–February 1997—Continued

Property or constituent	Number of samples	Median value	Mean value[1]	Standard deviation[1]	Minimum value	Maximum value	Minimum reporting level	Number below reporting level
08077648 Gum Bayou at Farm Road 1266 near League City, Tex.								
Instantaneous streamflow (ft^3/s)	4	0.01	0.25	0.48	0.01	0.97	na	na
Temperature (°C)	4	24.7	24.1	6.0	17.0	30.0	na	na
Specific conductance (µS/cm)	4	437	422	107	281	532	na	na
pH (standard units)	4	7.8	7.8	.4	7.4	8.3	na	na
Dissolved oxygen (mg/L)	3	9.0	6.9	4.2	2.0	9.7	na	na
Alkalinity (mg/L as CaCO$_3$)	4	180	168	33.0	120	190	na	na
5-day biochemical oxygen demand[2] (mg/L)	3	4	3.7	1.5	2	5	na	na
Fecal coliform bacteria[2] (cols./100 mL)	4	170	165	140	<20	300	20	1
Toxicity[3] (TU)	4	0	0	na	na	na	na	na
Dissolved ammonia nitrogen (mg/L)	4	.020	.028	.022	<.015	.060	.015	1
Dissolved nitrite nitrogen (mg/L)	4	<.01	.01	0	<.01	<.01	.01	4
Dissolved Kjeldahl nitrogen (mg/L)	4	.65	.65	.13	.50	.80	.20	0
Total Kjeldahl nitrogen (mg/L)	4	1.0	1.1	.28	.60	1.2	.20	0
Dissolved nitrite plus nitrate nitrogen (mg/L)	4	<.050	.050	0	<.050	<.050	.050	4
Total phosphorus (mg/L)	4	.050	.052	.026	.030	.080	.010	0
Dissolved phosphorus (mg/L)	4	<.010	.010	0	<.010	<.010	.010	4
Dissolved orthophosphate (mg/L)	4	<.010	.010	0	<.010	<.010	.010	4
Suspended sediment (mg/L)	4	61.5	764	1,430	24.0	2,910	na	na

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[1] All laboratory results reported as below minimum reporting level were set equal to minimum reporting level before computation of statistic.

[2] Laboratory analysis by Galveston County Health District.

[3] Laboratory analysis by City of League City using microtox.

Table 6. Summary statistics of water-quality data for selected storm events for fixed stations, Dickinson Bayou near Houston, Texas, March 1995–February 1997

[°C, degrees Celsius; na, not available; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; cols./100 mL, colonies per 100 milliliters; >, greater than; TU, U.S. Environmental Protection Agency toxicity units; <, less than]

Property or constituent (unit of measure)	Number of samples	Median value	Mean value[1]	Standard deviation[1]	Minimum value	Maximum value	Reporting level		Number below reporting level	Number above reporting level
							Minimum	Maximum		
08077642 Drainage ditch at Leisure Ln. near Alvin, Tex.										
Temperature (°C)	0	na	na	na	na	na	na	na	na	na
Specific conductance (µS/cm)	10	116	129	47	65	208	na	na	na	na
pH (standard units)	4	7.2	7.1	.5	6.4	7.5	na	na	na	na
Dissolved oxygen (mg/L)	0	na	na	na	na	na	na	na	na	na
Alkalinity (mg/L as $CaCO_3$)	4	41	41	16	21	61	na	na	na	na
5-day biochemical oxygen demand[2] (mg/L)	5	5	5.6	2.5	4	10	na	10	na	0
Fecal coliform bacteria[2] (cols./100 mL)	6	>16,000	na	na	170	>16,000	na	16,000	na	4
Toxicity[3] (TU)	4	0	0	na	na	na	na	na	na	na
Dissolved ammonia nitrogen (mg/L)	31	.02	.075	.200	<.015	1.10	0.015	na	15	na
Dissolved nitrite nitrogen (mg/L)	31	<.01	.01	.01	<.01	.08	.01	na	21	na
Dissolved Kjeldahl nitrogen (mg/L)	31	.50	.71	.78	<.20	4.50	.20	na	1	na
Total Kjeldahl nitrogen (mg/L)	31	.80	1.51	1.85	.30	9.3	.20	na	0	na
Dissolved nitrite plus nitrate nitrogen (mg/L)	31	<.050	.10	.08	<.050	.33	.050	na	19	na
Total phosphorus (mg/L)	31	.12	.11	.06	.030	.26	.010	na	0	na
Dissolved phosphorus (mg/L)	31	.04	.05	.04	<.010	.14	.010	na	6	na
Dissolved orthophosphate (mg/L)	31	.04	.05	.04	<.010	.11	.010	na	3	na
Suspended sediment (mg/L)	22	65	151	172	21.0	671	na	na	na	na

Footnotes at end of table.

Table 6. Summary statistics of water-quality data for selected storm events for fixed stations, Dickinson Bayou near Houston, Texas, March 1995–February 1997—Continued

Property or constituent (unit of measure)	Number of samples	Median value	Mean value[1]	Standard deviation[1]	Minimum value	Maximum value	Reporting level		Number below reporting level	Number above reporting level
							Minimum	Maximum		
08077644 Drainage Ditch 9C at Fourth St. near Santa Fe, Tex.										
Temperature (°C)	0	na	na	na	na	na	na	na	na	na
Specific conductance (µS/cm)	13	211	307	220	78	720	na	na	na	na
pH (standard units)	4	7.6	7.6	.2	7.4	7.9	na	na	na	na
Dissolved oxygen (mg/L)	0	na	na	na	na	na	na	na	na	na
Alkalinity (mg/L as $CaCO_3$)	4	76.5	110	99.3	36	250	na	na	na	na
5-day biochemical oxygen demand[2] (mg/L)	5	3	4.4	1.9	3	7	na	10	na	0
Fecal coliform bacteria[2] (cols./100 mL)	6	>16,000	na	na	170	>16,000	na	16,000	na	4
Toxicity[3] (TU)	4	0	0	na	na	na	na	na	na	na
Dissolved ammonia nitrogen (mg/L)	32	.02	.04	.04	<.015	.20	0.015	na	13	na
Dissolved nitrite nitrogen (mg/L)	32	.01	.01	.01	<.01	.03	.01	na	14	na
Dissolved Kjeldahl nitrogen (mg/L)	32	.50	.50	.12	.30	.80	.20	na	0	na
Total Kjeldahl nitrogen (mg/L)	32	.80	.79	.21	.40	1.2	.20	na	0	na
Dissolved nitrite plus nitrate nitrogen (mg/L)	32	.11	.14	.12	<.050	.66	.050	na	7	na
Total phosphorus (mg/L)	32	.17	.19	.08	.070	.340	.010	na	0	na
Dissolved phosphorus (mg/L)	20	.12	.13	.07	.030	.280	.010	na	0	na
Dissolved orthophosphate (mg/L)	32	.12	.13	.07	.010	.30	.010	na	0	na
Suspended sediment (mg/L)	18	94	106	63.6	20.0	261	na	na	na	na

Footnotes at end of table.

Table 6. Summary statistics of water-quality data for selected storm events for fixed stations, Dickinson Bayou near Houston, Texas, March 1995–February 1997—Continued

Property or constituent (unit of measure)	Number of samples	Median value	Mean value[1]	Standard deviation[1]	Minimum value	Maximum value	Reporting level		Number below reporting level	Number above reporting level
							Minimum	Maximum		
08077646 Central St. Drainage Ditch at Dickinson, Tex.										
Temperature (°C)	0	na	na	na	na	na	na	na	na	na
Specific conductance (µS/cm)	16	370	422	261	132	808	na	na	na	na
pH (standard units)	4	7.7	7.6	.1	7.4	7.7	na	na	na	na
Dissolved oxygen (mg/L)	0	na	na	na	na	na	na	na	na	na
Alkalinity (mg/L as $CaCO_3$)	4	94.0	96.5	57.9	38	160	na	na	na	na
5-day biochemical oxygen demand[2] (mg/L)	4	4.5	5	2.4	3	8	na	10	na	0
Fecal coliform bacteria[2] (cols./100 mL)	4	>16,000	na	na	3,000	>16,000	na	16,000	na	3
Toxicity[3] (TU)	3	0	0	na	na	na	na	na	na	na
Dissolved ammonia nitrogen (mg/L)	32	.02	.03	.02	<.015	.090	0.015	na	14	na
Dissolved nitrite nitrogen (mg/L)	32	.02	.02	.01	<.01	.06	.01	na	5	na
Dissolved Kjeldahl nitrogen (mg/L)	32	.40	.46	.26	<.20	1.0	.20	na	3	na
Total Kjeldahl nitrogen (mg/L)	32	.80	.98	.61	.30	3.3	.20	na	0	na
Dissolved nitrite plus nitrate nitrogen (mg/L)	32	.24	.25	.13	.05	.56	.050	na	0	na
Total phosphorus (mg/L)	32	.18	.24	.14	.09	.69	.010	na	0	na
Dissolved phosphorus (mg/L)	32	.08	.13	.10	.03	.37	.010	na	0	na
Dissolved orthophosphate (mg/L)	32	.07	.10	.08	.02	.29	.010	na	0	na
Suspended sediment (mg/L)	21	64.0	97.3	82.8	11.0	281	na	na	na	na

Footnotes at end of table.

Table 6. Summary statistics of water-quality data for selected storm events for fixed stations, Dickinson Bayou near Houston, Texas, March 1995–February 1997—Continued

Property or constituent (unit of measure)	Number of samples	Median value	Mean value[1]	Standard deviation[1]	Minimum value	Maximum value	Reporting level		Number below reporting level	Number above reporting level
							Minimum	Maximum		
08077648 Gum Bayou at Farm Road 1266 near League City, Tex.										
Temperature (°C)	0	na	na	na	na	na	na	na	na	na
Specific conductance (µS/cm)	9	165	208	170	39	595	na	na	na	na
pH (standard units)	3	7.9	7.6	.8	6.7	8.1	na	na	na	na
Dissolved oxygen (mg/L)	0	na	na	na	na	na	na	na	na	na
Alkalinity (mg/L as $CaCO_3$)	3	90	110	111	10	230	na	na	na	na
5-day biochemical oxygen demand[2] (mg/L)	4	3	4	2	3	7	na	10	na	0
Fecal coliform bacteria[2] (cols./100 mL)	6	>16,000	na	na	1,700	>16,000	na	16,000	na	4
Toxicity[3] (TU)	4	0	0	na	na	na	na	na	na	na
Dissolved ammonia nitrogen (mg/L)	32	<.015	.025	.020	<.015	.090	0.015	na	19	na
Dissolved nitrite nitrogen (mg/L)	32	<.01	.01	.01	<.01	.04	.01	na	16	na
Dissolved Kjeldahl nitrogen (mg/L)	32	.50	.45	.13	<.20	.70	.20	na	1	na
Total Kjeldahl nitrogen (mg/L)	32	.70	.72	.23	.20	1.2	.20	na	0	na
Dissolved nitrite plus nitrate nitrogen (mg/L)	32	.05	.08	.06	<.50	.24	.050	na	15	na
Total phosphorus (mg/L)	32	.03	.03	.03	<.01	.11	.010	na	10	na
Dissolved phosphorus (mg/L)	32	<.01	.01	.01	<.01	.03	.010	na	23	na
Dissolved orthophosphate (mg/L)	32	<.01	.01	.00	<.01	.03	.010	na	27	na
Suspended sediment (mg/L)	26	72.5	288	703	10.0	3,420	na	na	na	na

[1] All laboratory results reported as below minimum reporting level were set equal to minimum reporting level for all subsequent computations.

[2] Laboratory analysis by Galveston County Health District.

[3] Laboratory analysis by City of League City using microtox.

Table 7a. Streamflow and water-quality properties for selected stations, Dickinson Bayou near Houston, Texas, low-flow synoptic survey August 22, 1995

[ft^3/s, cubic feet per second; °C, degrees Celsius; μS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; CaCO$_3$, calcium carbonate; cols./100 mL, colonies per 100 milliliters; TU, U.S. Environmental Protection Agency toxicity units; USEPA, U.S. Environmental Protection Agency; na, not available]

USGS station number	Instantaneous streamflow (ft^3/s)	Water temperature (°C)	Specific conductance (μS/cm)	pH (standard units)	Dissolved oxygen (mg/L)	Alkalinity (mg/L as CaCO$_3$)	5-day biochemical oxygen demand (mg/L)[1]	Fecal coliform bacteria (cols./100 mL)[1]	Toxicity (TU)[2]	Toxicity (percent organisms affected)
08077638	1.54	27.7	617	7.9	5.4	154	1	20	0	[3]7
08077640	20.1	27.8	610	8.2	5.8	167	1	210	0	[3]7
08077643	39.0	29.9	604	8.2	5.3	166	1	230	0	[3]3
08077644	.01	29.5	697	7.0	8.7	198	2	20	0	na
08077645	39.8	29.0	12,000	8.3	4.5	184	8	500	0	[4]0
08077646	.01	29.5	653	8.7	8.8	198	3	3,000	0	na
08077647	-126	32.9	13,500	8.9	4.5	194	5	800	0	[4]0
08077649	-34.7	34.7	13,000	8.5	na	154	4	500	0	[4]7

[1] Laboratory analysis by Galveston County Health District.

[2] Laboratory analysis by City of League City using microtox.

[3] Laboratory analysis by USEPA using biomonitoring analysis—7-day embryo/larval test using *Pimephales promelas*. Results expressed as percent organisms affected (composite number of dead embryos (unhatched) and larvae, as well as organisms exhibiting anomalous form or abnormal swimming behavior).

[4] Laboratory analysis by USEPA using biomonitoring analysis—9-day embryo/larval test using *Cyprinodon variegatus*. Results expressed as percent organisms affected (composite number of dead embryos (unhatched) and larvae, as well as organisms exhibiting anomalous form or abnormal swimming behavior).

Table 7b. Nutrient and suspended-sediment concentrations for selected stations, Dickinson Bayou near Houston, Texas, low-flow synoptic survey August 22, 1995

[mi, miles; mg/L, milligrams per liter; <, less than; na, not available]

USGS station number	Distance from mouth of bayou (mi)	Dissolved ammonia nitrogen (mg/L)	Dissolved nitrite nitrogen (mg/L)	Dissolved Kjeldahl nitrogen (mg/L)	Total Kjeldahl nitrogen (mg/L)	Dissolved nitrite plus nitrate nitrogen (mg/L)	Total phosphorus (mg/L)	Dissolved phosphorus (mg/L)	Dissolved orthophosphate (mg/L)	Suspended sediment (mg/L)
08077638	22.73	0.090	0.030	0.80	<0.20	2.40	0.450	0.170	0.450	34
08077640	17.42	.030	.010	.90	<.20	.200	.100	.090	.050	74
08077643	11.55	.020	<.010	.80	<.20	.140	.050	.050	.040	26
08077644	na	.020	<.010	1.0	<.20	<.050	.010	.010	<.010	na
08077645	8.71	.100	<.010	na	na	<.050	.180	.010	.170	na
08077646	na	<.015	<.010	.70	<.20	<.050	<.010	.010	<.010	na
08077647	5.68	<.015	<.010	na	na	.070	.010	.010	.150	31
08077649	3.60	<.015	<.010	.70	<.20	<.050	.120	.120	.060	na

Table 7c. Nutrient concentrations in bottom-sediment samples for selected stations, Dickinson Bayou near Houston, Texas, low-flow synoptic survey August 22, 1995

[mg/kg, milligrams per kilogram]

USGS station number	Ammonia nitrogen (mg/kg)	Kjeldahl nitrogen (mg/kg)	Nitrite plus nitrate nitrogen (mg/kg)	Phosphorus (mg/kg)
08077638	13	550	7.0	240
08077640	10	680	2.0	750
08077643	46	1,600	2.0	290
08077645	5.4	770	7.0	150
08077647	13	420	4.0	90
08077649	1.8	700	7.0	81

Table 8a. Streamflow and water-quality properties for selected stations, Dickinson Bayou near Houston, Texas, high-flow synoptic survey January 27–29, 1997

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; CaCO$_3$, calcium carbonate; cols./100 mL, colonies per 100 milliliters; TU, U.S. Environmental Protection Agency toxicity units; na, not available]

USGS station number	Sample-collection date and time	Instantaneous streamflow (ft^3/s)	Specific conductance (µS/cm)	pH (standard units)	Water temperature (°C)	Alkalinity (mg/L as CaCO$_3$)	5-day biochemical oxygen demand (mg/L)[1]	Fecal coliform bacteria (cols./100 mL)[1]	Toxicity (TU)[2]
08077638	1/27/97 1942	0.04	174	7.2	27.2	202	5	[3]16,000	0
	1/28/97 0734	103	188	5.8	26.8	26.2	na	na	na
	1/29/97 0758	9.96	294	6.6	26.2	31.2	na	na	na
08077647	1/27/97 2132	396	797	7.7	28.0	95.1	4	[3]16,000	0
	1/28/97 1151	4750	257	7.5	27.5	41.0	na	na	na
	1/29/97 1152	529	178	7.5	27.1	39.4	na	na	na

[1] Laboratory analysis by Galveston County Health District.

[2] Laboratory analysis by City of League City using microtox.

[3] Maximum reporting level 16,000 cols./100 mL.

Table 8b. Nutrient and suspended-sediment concentrations for selected stations, Dickinson Bayou near Houston, Texas, high-flow synoptic survey January 27–29, 1997

[mg/L, milligrams per liter; <, less than]

USGS station number	Sample collection date and time	Dissolved ammonia nitrogen (mg/L)	Dissolved nitrite nitrogen (mg/L)	Dissolved Kjeldahl nitrogen (mg/L)	Total Kjeldahl nitrogen (mg/L)	Dissolved nitrite plus nitrate nitrogen (mg/L)	Total phosphorus (mg/L)	Dissolved phosphorus (mg/L)	Dissolved orthophosphate (mg/L)	Suspended sediment (mg/L)
08077638	1/27/97 1942	<0.015	0.020	0.50	1.0	0.080	0.200	0.140	0.130	66
	1/28/97 0734	<.015	.020	.60	1.0	1.90	.240	.230	.200	73
	1/29/97 0758	<.015	<.010	.40	.70	<.050	.070	.020	.020	79
08077647	1/27/97 2132	.100	.030	.60	1.1	.100	.190	.080	.080	86
	1/28/97 1151	.030	.020	.50	1.2	.070	.210	.060	.070	101
	1/29/97 1152	<.015	.010	.50	.80	<.050	.100	.050	.050	324

Table 9. Computed loads and yields of selected nutrients for four fixed stations, Dickinson Bayou near Houston, Texas, March 1995–February 1997

[RURAL/RES, rural/residential; RURAL/MIX, rural/mixed; lb/d, pounds per day; (lb/d)/mi^2, pounds per day per square mile]

Constituent	08077642 RURAL/RES		08077644 RURAL/MIX		08077646 URBAN		08077648 PASTURE	
	Load (lb/d)	Yield [(lb/d)/mi^2]	Load (lb/d)	Yield [(lb/d)/mi^2]	Load (lb/d)	Yield [(lb/d)/mi^2]	Load (lb/d)	Yield [(lb/d)/mi^2]
Dissolved ammonia nitrogen	0.0328	0.0476	0.230	0.0991	0.0410	0.103	0.129	0.0919
Dissolved nitrite nitrogen	.0274	.0397	.150	.0649	.0547	.137	.0711	.0508
Dissolved Kjeldahl nitrogen	1.27	1.85	5.94	2.56	1.15	2.87	2.90	2.07
Total Kjeldahl nitrogen	2.52	3.65	8.45	3.64	2.02	5.06	5.32	3.80
Dissolved organic nitrogen	1.23	1.78	5.70	2.46	1.11	2.77	2.78	1.98
Dissolved nitrite plus nitrate nitrogen	.134	.194	.996	.430	.544	1.36	.432	.309
Total nitrogen	2.65	3.85	9.45	4.07	2.57	6.43	5.76	4.11
Total phosphorus	.337	.487	2.20	.949	.484	1.21	.219	.156
Dissolved phosphorus	.202	.293	1.66	.713	.287	.718	.0793	.0567
Dissolved orthophosphate	.161	.234	1.60	.690	.224	.561	.0711	.0508

Table 10. Estimates of total nonpoint-source nutrient loads to Dickinson Bayou near Houston, Texas, March 1995–February 1997

[lb/d, pounds per day]

Constituent or property	Load (lb/d)
Dissolved ammonia nitrogen	7.84
Dissolved nitrite nitrogen	5.79
Dissolved Kjeldahl nitrogen	215
Total Kjeldahl nitrogen	350
Dissolved nitrite plus nitrate nitrogen	40.1
Total nitrogen	390
Total phosphorus	67.6
Dissolved phosphorus	46.6
Dissolved orthophosphate	42.8

Table 11. Summary of statistical comparisons of nutrient concentrations, Dickinson Bayou near Houston, Texas, 1995–97

[RURAL/RES, rural residential land use; RURAL/MIX, rural mixed land use; --, not tested; Y, yes—significant differences are between concentrations grouped on the basis of flow condition (high flow or low flow), season, or land use; N, no—no significant differences]

Nutrient	Intra-station comparisons								Interstation comparisons
	08077642 RURAL/RES		08077644 RURAL/MIX		08077646 URBAN		08077648 PASTURE		
	Flow condition	Season	Flow condition	Season	Flow condition	Season	Flow condition	Season	Land use
Dissolved ammonia nitrogen	--	Y	Y	Y	N	N	N	Y	N
Dissolved nitrite nitrogen	--	N	Y	N	Y	N	N	N	Y
Dissolved Kjeldahl nitrogen	--	N	Y	N	N	N	Y	N	N
Total Kjeldahl nitrogen	--	N	Y	N	Y	Y	Y	Y	Y
Dissolved nitrite plus nitrate nitrogen	--	N	Y	N	Y	N	N	N	Y
Total phosphorus	--	Y	Y	N	Y	N	N	Y	Y
Dissolved phosphorus	--	N	Y	N	Y	N	N	N	Y
Dissolved orthophosphate	--	Y	Y	N	Y	Y	N	N	Y

Table 12. Algal and dissolved oxygen relations in Dickinson Bayou near Houston, Texas, low-flow synoptic survey August 22, 1995

[cm^2, square centimeter; mg/m^2, milligrams per square meter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than; >, greater than]

USGS station number	Algal cell counts (cells/cm^2 x 10^6)	Chlorophyll *a* (mg/m^2)	Chlorophyll *b* (mg/m^2)	Ratio of chlorophyll *a* to chlorophyll *b*	Dissolved oxygen (mg/L)	Dissolved oxygen (percent saturation)	Soil algae (percent)	Nitrogen-fixing algae (percent)
Specific conductance less than 1,000 µS/cm								
08077638	1.8	50	8.2	6.1	5.4	68	49	7
08077640	1.1	31	2.2	14.1	5.8	73	54	5
08077643	1.3	24	.6	40	5.3	70	78	3
08077644	1.7	20	1.2	16.7	8.7	114	82	5
Specific conductance greater than 10,000 µS/cm								
08077645	1.9	53	<.1	>530	4.5	58	40	33
08077647	1.5	13	.1	130	4.5	63	69	2
08077649	1.1	10	.2	50	6.7	96	14	42

Appendix 1—
ALGAL IDENTIFICATION AND ENUMERATION DATA

Algal Identification and Quantification Data Sheet

USGS station name: Dickinson Bayou at Farm Road 528 near Alvin - Page 1 of 2
USGS station number: 08077638
Date collected: 9/7/95

Taxa	**No. of cells counted**	**Cells/cm^2**
Desmococcus Brand spp.	94	840,000
Oedogonium Link spp.	6	53,600
Scenedesmus Meyen spp.	2	17,900
Achnanthes exigua Grunow	80	38,900
Amphora ovalis var. *affinis* (Kützing) Van Heurck ex DeToni	1	490
Amphora sp. 1 VA	1	490
Caloneis lewisii Patrick	1	490
Chaetophora Schrank spp.	24	214,000
Cyclotella cf. *comensis* Grunow	1	490
Eunotia sp. 1 VA	1	490
Fragilaria brevistriata Grunow	5	2,430
Gomphonema Kützing spp.	11	98,200
Gomphonema cf. *affine* Kützing	1	490
Gomphonema parvulum Kützing	25	12,200
Lyrella pygmaea (Kützing) D.G. Mann	12	5,800
Navicula Bory sp.	10	89,300
Navicula capitata var. *hungarica* (Grunow) Ross	1	490
Navicula cf. *arenaria* Donkin	26	12,600
Navicula cf. *cincta* f. *minuta* Grunow in Van Heurck	8	3,890
Navicula circumtexta Meisten ex Hustedt	6	2,920
Navicula confervacea (Kützing) Grunow	9	4,370
Navicula cryptocephala var. *veneta* (Kützing) Rabenhorst	1	490
Navicula schroeterii Meister (= *N. symmetrica* Patrick)	2	970
Navicula seminuloides Hustedt	30	14,600
Navicula sp. 19 VA	4	1,940
Navicula sp. 2 VA	5	2,430
Navicula sp. 21 VA	3	1,460
Navicula sp. 22 VA	1	490
Navicula sp. 3 VA	1	490
Navicula sp. 4 VA	7	3,400
Navicula sp. 5 VA	3	1,460
Navicula sp. 6 VA	2	970
Navicula subminiscula Manguin	71	34,500

Algal Identification and Quantification Data Sheet

USGS station name: Dickinson Bayou at Farm Road 528 near Alvin - Page 2 of 2
USGS station number: 08077638
Date collected: 9/7/95

Taxa	**No. of cells counted**	**Cells/cm^2**
Navicula tenera Hustedt	5	2,430
Navicula tripunctata var. *schizonemoides* (Van Heurck) Patrick	39	19,000
Nitzschia Hassall spp.	2	17,900
Nitzschia amphibia Grunow	70	34,000
Nitzschia calida Grunow	5	2,430
Nitzschia cf. *amphibia* Grunow	1	490
Nitzschia cf. *sigma* (Kützing) W. Smith	1	8,930
Nitzschia compressa (Bailey) Boyer	1	490
Nitzschia filiformis var. *conferta* (Richter) Lange-Bertalot	1	490
Nitzschia fonticola Grunow	3	1,460
Nitzschia frustulum (Kützing) Grunow	15	7,290
Nitzschia microcephala Grunow	5	2,430
Nitzschia palea (Kützing) W. Smith	8	3,890
Nitzschia pseudofonticola Hustedt	6	2,920
Nitzschia pusilla Grunow	81	39,400
Nitzschia siliqua Archibald	7	3,400
Nitzschia sp. 13 VA	4	1,940
Nitzschia sp. 2 VA	14	6,800
Nitzschia sp. 3 VA	2	970
Sellaphora pupula (Kützing) D.G. Mann	30	14,600
Sellaphora pupula var. *rectangularis* (Grunow) D.G. Mann	2	970
Tryblionella littoralis (Grunow in Cleve & Grunow) D.G. Mann	1	490
diatom spp.	4	35,700
Anabaina licheniformis Bory de Saint-Vincent	54	482,000
Anacystis montana (Lightfoot) Drouet & Dailey	224	2,000,000
Microcoleus vaginatus (Vaucher) Gomont	56	500,000
Schizothrix calcicola (Agardh) Gomont	275	2,460,000

Algal Identification and Quantification Data Sheet

USGS station name: Dickinson Bayou at Farm Road 517 near Alvin - Page 1 of 2
USGS station number: 08077640
Date collected: 9/7/95

Taxa	**No. of cells counted**	**Cells/cm^2**
Chlamydomonas Ehrenberg spp.	5	68,100
Cladophora Kützing sp.	9	123,000
Desmococcus Brand spp.	4	54,500
Achnanthes exigua Grunow	4	132
Achnanthes hauckiana Grunow	1	33
Achnanthes sp. 1 VA	1	33
Amphora acutiscula Kützing	1	33
Amphora angusta Gregory	61	2,010
Amphora sp. 1 VA	3	99
Cocconeis placentula var. *lineata* (Ehrenberg) Van Heurck	3	99
Cymbella Agardh/*Amphora* Ehrenberg spp.	7	95,300
Diploneis sp. 1 VA	2	66
Fragilaria brevistriata Grunow	2	66
Gomphonema Ehrenberg nom. cons. non Agardh sp. (large)	2	27,200
Gomphonema consector? Hohn & Hellerman	1	33
Gomphonema parvulum Kützing	2	27,200
Gomphosphenia Lange & Bertalot sp. 1 VA	9	123,000
Gomphosphenia lingulatiformis (Lange-Bertalot & Reichardt) Lange-Bertalot	73	2,410
Gyrosigma nodiferum (Grunow) G. West	13	429
Gyrosigma sp. 1 VA	1	33
Gyrosigma sp. 2 VA	1	33
Luticola mutica (Kützing) D.G. Mann	3	99
Navicula Bory sp.	12	163,000
Navicula auriculata Hustedt	2	66
Navicula capitata Ehrenberg	1	33
Navicula cf. *arenaria* Donkin	6	198
Navicula cf. *cincta* f. *minuta* Grunow in Van Heurck	25	825
Navicula cf. *cryptocephala* var. *veneta* (Kützing) Rabenhorst	2	66
Navicula cf. *seminuloides* Hustedt	2	66
Navicula crucicula (W. Smith) Donkin	1	33
Navicula seminuloides Hustedt	416	13,700
Navicula sp. 19 VA	2	66

Algal Identification and Quantification Data Sheet

USGS station name: Dickinson Bayou at Farm Road 517 near Alvin - Page 2 of 2
USGS station number: 08077640
Date collected: 9/7/95

Taxa	**No. of cells counted**	**Cells/cm^2**
Navicula sp. 2 VA	1	33
Navicula sp. 21 VA	1	33
Navicula sp. 6 VA	1	33
Navicula sp. 8 VA	3	99
Navicula subminiscula Manguin	11	363
Navicula tripunctata var. *schizonemoides* (Van Heurck) Patrick	52	1,720
Nitzschia Hassall spp.	6	81,700
Nitzschia amphibia Grunow	25	825
Nitzschia calida Grunow	4	132
Nitzschia compressa (Bailey) Boyer	1	33
Nitzschia filiformis var. *conferta* (Richter) Lange-Bertalot	3	99
Nitzschia fonticola Grunow	14	462
Nitzschia frustulum (Kützing) Grunow	32	1,060
Nitzschia inconspicua Grunow	1	33
Nitzschia microcephala Grunow	1	33
Nitzschia nana Grunow	1	33
Nitzschia palea (Kützing) W. Smith	1	33
Nitzschia pseudofonticola Hustedt	43	1,420
Nitzschia pusilla Grunow	24	792
Nitzschia reversa W. Smith	1	13,600
Nitzschia sigma (Kützing) W. Smith	1	13,600
Nitzschia siliqua Archibald	1	33
Nitzschia sp. 13 VA	1	33
Nitzschia sp. 4 VA	1	33
Nitzschia sp. 5 VA	1	33
Pleurosigma salinarum Grunow	5	165
S*ellaphora pupula* var. *rectangularis* (Grunow) D.G. Mann	1	33
Surirella Turpin (large)	1	13,600
Surirella inducta Hustedt	1	33
Synedra Ehrenberg (large)	1	13,600
Thalassiosira weissflogii (Grunow) Fryxell & Hasle	1	33
cryptomonad	6	81,700
Anabaina licheniformis Bory de Saint-Vincent	16	218,000
Anacystis montana (Lightfoot) Drouet & Dailey	11	150,000
Microcoleus vaginatus (Vaucher) Gomont	62	844,000
Schizothrix calcicola (Agardh) Gomont	184	2,500,000

Algal Identification and Quantification Data Sheet

USGS station name: Dickinson Bayou at Cemetary Rd. near Santa Fe - Page 1 of 2
USGS station number: 08077643
Date collected: 9/7/95

Taxa	**No. of cells counted**	**Cells/cm^2**
Ankistrodesmus Corda sp. (very thin 70 x1 µm)	1	14,000
Desmococcus Brand spp. (22-µm dia, 4 µm)	11	153,000
Scenedesmus Meyen sp.	2	27,900
coccoid chlorophyte (w/o sheath 4.5 µm)	2	27,900
coccoid chlorophyte (1.5-µm dia, 16 in a mother cell)	16	223,000
Amphora acutiscula Kützing	1	226
Amphora angusta Gregory	1	226
Amphora sp. 1 VA	2	452
Cyclotella aff. *comensis* Grunow	1	226
Cyclotella cf. *aliquantula* Hohn & Hellerman	3	678
Cymbella Agardh spp.	2	27,900
Denticula elegans Kützing	37	8,360
Diploneis sp. 1 VA	2	452
Diploneis sp. 2 VA	1	226
Fragilaria brevistriata Grunow	2	452
Hantzschia amphioxys (Ehrenberg) Grunow	1	14,000
Luticola mutica (Kützing) D.G. Mann	9	2,030
Navicula (*Diadesmis*?) *contenta* var. *biceps* (Arnott) Van Heurck	334	75,500
Navicula capitata Ehrenberg	1	226
Navicula cf. *cincta* f. *minuta* Grunow in Van Heurck	10	2,260
Navicula confervacea (Kützing) Grunow	1	226
Navicula cryptocephala Kützing	5	1,130
Navicula odiosa Wallace	3	678
Navicula sanctaecrucis Östrup	1	226
Navicula sp. 1 VA	3	678
Navicula sp. 11 VA	2	452
Navicula sp. 15 VA	9	2,030
Navicula sp. 16 VA	2	452
Navicula sp. 17 VA	1	226
Navicula sp. 2 VA	2	452
Navicula subminiscula Manguin	3	678
Navicula tenera Hustedt	1	226
Nitzschia? Hassall spp.	4	55,700

Algal Identification and Quantification Data Sheet

USGS station name: Dickinson Bayou at Cemetary Rd. near Santa Fe - Page 2 of 2
USGS station number: 08077643
Date collected: 9/7/95

Taxa	**No. of cells counted**	**Cells/cm^2**
Nitzschia acicularis (Kützing) W. Smith	1	226
Nitzschia amphibia Grunow	2	452
Nitzschia brevissima Grunow	44	9,940
Nitzschia fasciculata Grunow	6	1,360
Nitzschia filiformis var. *conferta* (Richter) Lange-Bertalot	16	3,620
Nitzschia fonticola Grunow	6	1,360
Nitzschia frustulum (Kützing) Grunow	14	3,160
Nitzschia frustulum (Kützing) Grunow ? (K&L-B 68/7)	2	452
Nitzschia frustulum (Kützing) Grunow ?2	2	452
Nitzschia lorenziana Grunow	1	226
Nitzschia obtusa var. *scalpelliformis* Grunow	3	678
Nitzschia pseudofonticola Hustedt	2	452
Nitzschia pusilla Grunow	47	10,600
Nitzschia romana Grunow	6	1,360
Nitzschia siliqua Archibald	3	678
Nitzschia sp. 14 VA	1	226
Nitzschia sp. 9 VA	1	226
Nitzschia tryblionella var. *salinarum* Grunow	5	1,130
Rhopalodia gibberula (Ehrenberg) O. Müller	1	226
Rhopalodia gibberula var. *vanheurckii* O. Müller	1	226
Rhopalodia musculus (Kützing) O. Müller	13	2,940
Sellaphora pupula (Kützing) D.G. Mann	2	452
Surirella inducta Hustedt	1	226
Thalassiosira weissflogii (Grunow) Fryxell & Hasle	1	226
diatom spp.	2	27,900
Calothrix Agardh spp.	11	153,000
Microcoleus vaginatus (Vaucher) Gomont	39	543,000
Schizothrix calcicola (Agardh) Gomont	270	3,760,000

Algal Identification and Quantification Data Sheet

USGS station name: Drainage Ditch 9C at Fourth St. near Santa Fe - Page 1 of 2
USGS station number: 08077644
Date collected: 9/7/95

Taxa	**No. of cells counted**	**Cells/cm^2**
Cosmarium Corda sp.	1	14,100
Rhizoclonium Kützing/*Cladophora* Kützing sp.	21	296,000
chlorophyte filament	25	352,000
coccoid chlorophyte (4 µm)	2	28,200
Achnanthes exigua Grunow	24	4,500
Amphora angusta Gregory	1	188
Anomoeoneis sphaerophora (Ehrenberg) Pfitzer	5	938
Caloneis bacillum Grunow	4	750
Cyclotella cf. *aliqantula* Hohn & Hellerman	3	563
Fragilaria brevistriata Grunow	1	188
Gomphonema parvulum Kützing	17	3,190
Gomphonema subclavatum var. *commutatum* (Grunow) A. Mayer	12	2,250
Gomphosphenia lingulatiformis (Lange-Bertalot & Reichardt) Lange-Bertalot	1	188
Luticola mutica (Kützing) D.G. Mann	1	188
Navicula auriculata Hustedt	4	750
Navicula cf. *arenaria* Donkin	1	188
Navicula cf. *cincta* f. *minuta* Grunow in Van Heurck	3	563
Navicula cf. *phyllepta* Kützing	1	188
Navicula circumtexta Meisten ex Hustedt	1	188
Navicula seminuloides Hustedt	20	3,750
Navicula seminulum Grunow	2	375
Navicula sp. 17 VA	1	188
Navicula sp. 19 VA	2	375
Navicula sp. 20 VA	1	188
Navicula sp. 22 VA	2	375
Navicula sp. 7 VA	3	563
Navicula tenera Hustedt	1	188
Navicula tripunctata var. *schizonemoides* (Van Heurck) Patrick	4	750

Algal Identification and Quantification Data Sheet

USGS station name: Drainage Ditch 9C at Fourth St. near Santa Fe - Page 2 of 2
USGS station number: 08077644
Date collected: 9/7/95

Taxa	**No. of cells counted**	**Cells/cm^2**
Nitzschia amphibia Grunow	346	64,900
Nitzschia calida Grunow	2	375
Nitzschia cf. *fonticola* (large)	1	188
Nitzschia compressa (Bailey) Boyer	1	188
Nitzschia filiformis var. *conferta* (Richter) Lange-Bertalot	2	375
Nitzschia fonticola Grunow	6	1,120
Nitzschia frustulum (Kützing) Grunow	62	11,600
Nitzschia frustulum (Kützing) Grunow ? (K&L-B 68/7)	2	375
Nitzschia liebetruthii Rabenhorst	1	188
Nitzschia microcephala Grunow	2	375
Nitzschia palea (Kützing) W. Smith	5	938
Nitzschia palea (Kützing) W. Smith ?	2	375
Nitzschia siliqua Archibald	31	5,810
Nitzschia sp. 10 VA	1	188
Rhopalodia gibba (Ehrenberg) O. Müller	2	375
Rhopalodia gibberula (Ehrenberg) O. Müller	9	1,690
Rhopalodia gibberula var. *vanheurckii* O. Müller	8	1,500
Synedra ulna var. 1	3	563
Tabularia fasciculata (Kützing) Williams & Round	1	188
diatom sp.	8	113,000
Peridinium Ehrenberg sp.	1	14,100
Anacystis montana (Lightfoot) Drouet & Dailey	14	197,000
Calothrix parietina (Nägeli ex Kützing) Thuret	23	324,000
Schizothrix calcicola (Agardh) Gomont	421	5,930,000

Algal Identification and Quantification Data Sheet

USGS station name: Drainage Ditch 9C at Fourth St. near Santa Fe - Page 1 of 2
USGS station number: 08077644
Date collected: 9/7/95 - replicate sample

Taxa	**No. of cells counted**	**Cells/cm^2**
Ankistrodesmus Corda sp.	1	9,760
Desmococcus Brand spp.	29	283,000
Scenedesmus Meyen sp.	4	39,000
Achnanthes exigua Grunow	12	1,730
Achnanthes lanceolata (Brebisson) Grunow	1	145
Achnanthes lanceolata ssp. *frequentissima* Lange-Bertalot	1	145
Anomoeoneis sphaerophora (Ehrenberg) Pfitzer	2	289
Cocconeis placentula var. *lineata* (Ehrenberg) Van Heurck	4	578
Cyclotella cf. *aliquantula* Hohn & Hellerman	2	289
Fragilaria brevistriata Grunow	2	289
Gomphonema cf. *affine* Kützing	1	145
Gomphonema gracile Ehrenberg amend. Van Heurck	1	145
Gomphonema parvulum Kützing	11	1,590
Gomphonema subclavatum var. *commutatum* (Grunow) A. Mayer	1	145
Gomphosphenia Lange-Bertalot sp.?	1	9,760
Gomphosphenia lingulatiformis (Lange-Bertalot & Reichardt) Lange-Bertalot	1	145
Luticola mutica (Kützing) D.G. Mann	1	145
Lyrella pygmaea (Kützing) D.G. Mann	1	145
Navicula cf. *cincta* f. *minuta* Grunow in Van Heurck	2	289
Navicula cf. *elginensis* var. lata (A. Mayer) Patrick	1	145
Navicula circumtexta Meisten ex Hustedt	1	145
Navicula sanctaecrucis Östrup	1	145
Navicula seminuloides Hustedt	15	2,170
Navicula sp. 21 VA	5	723
Navicula tenera Hustedt	1	145
Navicula tripunctata var. *schizonemoides* (Van Heurck) Patrick	2	289

Algal Identification and Quantification Data Sheet

USGS station name: Drainage Ditch 9C at Fourth St. near Santa Fe - Page 2 of 2
USGS station number: 08077644
Date collected: 9/7/95 - replicate sample

Taxa	**No. of cells counted**	**Cells/cm^2**
Nitzschia Hassall spp.	4	39,000
Nitzschia amphibia Grunow	397	57,400
Nitzschia compressa var. *elongata* (Grunow) Lange-Bertalot	2	289
Nitzschia fonticola Grunow	12	1,730
Nitzschia frustulum (Kützing) Grunow	48	6,940
Nitzschia inconspicua Grunow	2	289
Nitzschia liebetruthii Rabenhorst	5	723
Nitzschia microcephala Grunow	1	145
Nitzschia palea (Kützing) W. Smith	9	1,300
Nitzschia siliqua Archibald	14	2,020
Nitzschia sp. 10 VA	1	145
Rhopalodia gibba (Ehrenberg) O. Müller	2	289
Rhopalodia gibberula (Ehrenberg) O. Müller	22	3,180
Rhopalodia gibberula var. *vanheurckii* O. Müller	11	1,590
Sellaphora pupula (Kützing) D.G. Mann	1	145
Sellaphora pupula var. *rectangularis* (Grunow) D.G. Mann	1	145
Synedra ulna var. 1	1	145
Tabularia fasciculata (Kützing) Williams & Round	2	289
diatom spp.	3	29,300
Peridinium Ehrenberg sp.	1	9,760
cryptomonad spp.	3	29,300
Anacystis montana (Lightfoot) Drouet & Dailey	12	117,000
Calothrix parietina (Nägeli ex Kützing) Thuret	25	244,000
Schizothrix calcicola (Agardh) Gomont	323	3,150,000

Algal Identification and Quantification Data Sheet

USGS station name: Dickinson Bayou at I–45 at Dickinson - Page 1 of 2
USGS station number: 08077645
Date collected: 9/8/95

Taxa	**No. of cells counted**	**Cells/cm^2**
Desmococcus Brand spp.	40	495,000
Achnanthes hauckiana Grunow	1	14
Amphora acutiscula Kützing	2	27
Amphora angusta Gregory	31	419
Amphora ovalis var. *affinis* (Kützing) Van Heurck in DeToni	8	108
Bacillaria paradoxa Gmelin	20	270
Denticula elegans Kützing	14	189
Diploneis sp. 1 VA	5	68
Fragilaria brevistriata Grunow	1	14
Fragilaria brevistriata var. 1	1	14
Fragilaria subsalina (Grunow) Lange-Bertalot	1	14
Gomphonema cf. *tenellum* Kützing	1	14
Gomphonema parvulum Kützing	1	14
Gomphosphenia lingulatiformis (Lange-Bertalot & Reichardt) Lange-Bertalot	4	54
Hantzschia amphioxys (Ehrenberg) Grunow	1	14
Luticola mutica (Kützing) D.G. Mann	37	500
Navicula (Diadesmis?) contenta var. *biceps* (Arnott) Van Heurck	15	203
Navicula capitata Ehrenberg	2	27
Navicula capitata var. *hungarica* (Grunow) Ross	1	14
Navicula cf. *cincta* f. *minuta* Grunow in Van Heurck	17	230
Navicula protracta (Grunow) Cleve	3	41
Navicula semen Ehrenberg	1	14
Navicula sp. 16 VA	2	27
Navicula sp. 2 VA	1	14
Navicula sp. 21 VA	19	257
Navicula tenera Hustedt	2	27
Navicula tripunctata var. *schizonemoides* (Van Heurck) Patrick	12	162

Algal Identification and Quantification Data Sheet

USGS station name: Dickinson Bayou at I–45 at Dickinson - Page 2 of 2
USGS station number: 08077645
Date collected: 9/8/95

Taxa	**No. of cells counted**	**Cells/cm^2**
Nitzschia amphibia Grunow	3	41
Nitzschia fasciculata Grunow	10	135
Nitzschia filiformis var. *conferta* (Richter) Lange-Bertalot	10	135
Nitzschia fonticola Grunow	5	68
Nitzschia frustulum (Kützing) Grunow	17	230
Nitzschia liebetruthii Rabenhorst	1	14
Nitzschia lorenziana Grunow	1	14
Nitzschia obtusa W. Smith	11	149
Nitzschia palea (Kützing) W. Smith	2	27
Nitzschia palea (Kützing) W. Smith ?	4	54
Nitzschia paleacea Grunow	1	14
Nitzschia pusilla Grunow	1	14
Nitzschia sp. 10 VA	2	27
Nitzschia sp. 7 VA	2	27
Nitzschia tryblionella var. *debilis* (Arnott) Hustedt	6	81
Nitzschia tryblionella var. *salinarum* Grunow	2	27
Rhopalodia gibba (Ehrenberg) O. Müller	1	14
Rhopalodia gibberula (Ehrenberg) O. Müller	13	176
Rhopalodia gibberula var. *vanheurckii* O. Müller	3	41
Rhopalodia musculus (Kützing) O. Müller	6	81
live diatoms	4	49,500
Calothrix parietina (Nägeli ex Kützing) Thuret	226	2,800,000
Lyngbya lagerheimii (Möbuis) Gomont	33	409,000
Microcoleus vaginatus (Vaucher) Gomont	40	495,000
Pleurocapsa minor Hansgirgs emend. Geitler	110	1,360,000
Schizothrix calcicola (Agardh) Gomont	235	2,910,000
coccoid cyanophyte (4 µm)	6	74,300

Algal Identification and Quantification Data Sheet

USGS station name: Dickinson Bayou at State Highway 3, Dickinson - Page 1 of 2
USGS station number: 08077647
Date collected: 9/8/95

Taxa	**No. of cells counted**	**Cells/cm^2**
Ankistrodesmus falcatus (Corda) Ralfs	1	7,490
Chlamydomonas Ehrenberg sp.	1	7,490
coccoid chlorophyte	2	15,000
Achnanthes amoena Hustedt	2	638
Achnanthes exigua Grunow	1	319
Achnanthes hauckiana Grunow	1	319
Achnanthes linearis (W. Smith) Grunow	3	957
Amphora acutiscula Kützing	50	16,000
Amphora angusta Gregory	63	20,100
Amphora ovalis var. *affinis* (Kützing) Van Heurck ex DeToni	3	957
Amphora sp. 3 VA	1	319
Bacillaria paradoxa Gmelin	3	957
Cocconeis Ehrenberg sp.	1	7,490
Cyclotella cf. *aliqantula* Hohn & Hellerman	5	1,600
Diatoma Bory nom. cons. non Loureiro sp.	1	7,490
Dimerogramma? *minor* (Gregory) Ralfs in Pritchard	1	319
Diploneis sp. 1 VA	12	3,830
Fragilaria brevistriata Grunow	8	2,550
Martyana ansata (Hohn & Hellerman) F.E. Round	7	2,230
Navicula Bory spp.	8	60,000
Navicula auriculata Hustedt	1	319
Navicula capitata var. *hungarica* (Grunow) Ross	4	1,280
Navicula cf. *cincta* f. *minuta* Grunow in Van Heurck	27	8,610
Navicula cf. *decussis* Östrup	34	10,900
Navicula cf. *phyllepta* Kützing	2	638
Navicula cryptocephala var. *veneta* (Kützing) Rabenhorst	1	319
Navicula heufleri Grunow	13	4,150
Navicula ilopangoensis Hustedt	19	6,060
Navicula odiosa Wallace	7	2,230
Navicula sanctaecrucis Östrup	1	319
Navicula schroeterii Meister (= *N. symmetrica* Patrick)	1	319
Navicula sp. 10 VA	2	638
Navicula sp. 11 VA	1	319
Navicula sp. 12 VA	5	1,600
Navicula sp. 13 VA	2	638
Navicula sp. 14 VA	9	2,870

Algal Identification and Quantification Data Sheet

USGS station name: Dickinson Bayou at State Highway 3, Dickinson - Page 2 of 2
USGS station number: 08077647
Date collected: 9/8/95

Taxa	**No. of cells counted**	**Cells/cm^2**
Navicula sp. 19 VA	3	957
Navicula sp. 2 VA	2	638
Navicula sp. 21 VA	5	1,600
Navicula sp. 3 VA	1	319
Navicula sp. 9 VA	4	1,280
Navicula subminiscula Manguin	1	319
Navicula tenera Hustedt	1	319
Navicula tripunctata var. *schizonemoides* (Van Heurck) Patrick	58	18,500
Nitzschia Hassall sp.	1	7,490
Nitzschia amphibia Grunow	1	319
Nitzschia calida Grunow	1	319
Nitzschia cf. *fonticola* (large)	2	638
Nitzschia communis Rabenhorst	4	1,280
Nitzschia fasciculata Grunow	1	319
Nitzschia filiformis var. *conferta* (Richter) Lange-Bertalot	24	7,660
Nitzschia fonticola Grunow	5	1,600
Nitzschia frustulum (Kützing) Grunow	124	39,600
Nitzschia frustulum (Kützing) Grunow ? K&L-B 58/7	6	1,910
Nitzschia frustulum (Kützing) Grunow ?2	6	1,910
Nitzschia inconspicua Grunow	9	2,870
Nitzschia microcephala Grunow	8	2,550
Nitzschia obtusa var. *scalpelliformis* Grunow	1	319
Nitzschia pusilla Grunow	8	2,550
Nitzschia romana Grunow	19	6,060
Nitzschia sp. 1 VA	39	12,400
Nitzschia sp. 7 VA	8	2,550
Nitzschia tryblionella var. *salinarum* Grunow	1	319
Rhopalodia gibberula var. *vanheurckii* O. Müller	2	638
Surirella Turpin sp.	1	7,490
Surirella inducta Hustedt	5	1,600
diatom sp.	1	7,490
Anacystis montana (Lightfoot) Drouet & Dailey	108	809,000
Calothrix parietina (Nägeli ex Kützing) Thuret	16	120,000
Lyngbya lagerheimii (Möbuis) Gomont	59	442,000
Lyngbya martensiana Meneghini	31	232,000
Schizothrix calcicola (Agardh) Gomont	517	3,870,000

Algal Identification and Quantification Data Sheet

USGS station name: Gum Bayou at Farm Road 517 near Texas City - Page 1 of 3
USGS station number: 08077649
Date collected: 9/8/95

Taxa	No. of cells counted	Cells/cm^2
Ankistrodesmus Corda sp.	1	5,270
Chlamydomonas spp.	3	15,800
Rhizoclonium Kützing sp.	4	21,100
Achnanthes hauckiana Grunow	4	2,960
Achnanthes linearis (W. Smith) Grunow	2	1,480
Achnanthes sp. 1 VA	1	740
Achnanthes sp. 2 VA	2	1,480
Amphora acutiscula Kützing	5	3,700
Amphora angusta Gregory	70	51,800
Amphora ovalis var. *affinis* (Kützing) Van Heurck ex DeToni	1	740
Amphora sp. 2 VA	4	2,960
Bacillaria paradoxa Gmelin	3	2,220
Cyclotella aff. *comensis* Grunow	8	5,920
Cyclotella cf. *aliquantula* Hohn & Hellerman	48	35,500
Cyclotella sp. 1 VA	69	51,100
Cyclotella striata (Kützing) Grunow	2	1,480
Cymbella Agardh/*Amphora* Ehrenberg spp.	4	21,100
Denticula elegans Kützing	1	740
Diploneis sp. 1 VA	7	5,180
Entomoneis alata (Ehrenberg) Ehrenberg	3	2,220
Fragilaria brevistriata Grunow	12	8,880
Fragilaria subsalina (Grunow) Lange-Bertalot (=*Fragilaria virescens* var. *subsalina* Grunow)	2	1,480
Lyrella pygmaea (Kützing) D.G. Mann	3	2,220
Martyana ansata (Hohn & Hellerman) F.E. Round	1	740
Navicula (*Diadesmis*?) *contenta* var. *biceps* (Arnott) Van Heurck	1	740
Navicula capitata var. *hungarica* (Grunow) Ross	3	2,220
Navicula capitata var. *luneburgensis* (Grunow) Patrick	1	740
Navicula cf. *arenaria* Donkin	3	2,220
Navicula cf. *cincta* f. *minuta* Grunow in Van Heurck	21	15,500
Navicula cf. *phyllepta* Kützing	22	16,300
Navicula cryptocephala var. *veneta* (Kützing) Rabenhorst	9	6,660
Navicula cryptocephala Kützing	1	740
Navicula heufleri Grunow	15	11,100

Algal Identification and Quantification Data Sheet

USGS station name: Gum Bayou at Farm Road 517 near Texas City - Page 2 of 3
USGS station number: 08077649
Date collected: 9/8/95

Taxa	**No. of cells counted**	**Cells/cm^2**
Navicula ilopangoensis Hustedt	1	740
Navicula odiosa Wallace	3	2,220
Navicula sanctaecrucis Östrup	2	1,480
Navicula sp. 1 VA	1	740
Navicula sp. 10 VA	9	6,660
Navicula sp. 13 VA	4	2,960
Navicula sp. 17 VA	1	740
Navicula sp. 19 VA	5	3,700
Navicula sp. 2 VA	1	740
Navicula sp. 20 VA	1	740
Navicula sp. 21 VA	3	2,220
Navicula sp. 9 VA	1	740
Navicula tenera Hustedt	4	2,960
Navicula tripunctata var. *schizonemoides* (Van Heurck) Patrick	11	8,140
Nitzschia Hassall sp.	4	21,100
Nitzschia amphibia Grunow	2	1,480
Nitzschia brevissima Grunow	2	1,480
Nitzschia cf. *fonticola* (large)	1	740
Nitzschia communis Rabenhorst	10	7,400
Nitzschia dissipata (Kützing) Grunow	2	1,480
Nitzschia filiformis var. *conferta* (Richter) Lange-Bertalot	13	9,620
Nitzschia fonticola Grunow	7	5,180
Nitzschia frustulum (Kützing) Grunow ? K&L-B 68/7	10	7,400
Nitzschia frustulum (Kützing) Grunow	33	24,400
Nitzschia hungarica Grunow	4	2,960
Nitzschia inconspicua Grunow	24	17,800
Nitzschia liebetruthii Rabenhorst	33	24,400
Nitzschia lorenziana Grunow	8	5,920
Nitzschia microcephala Grunow	1	740
Nitzschia nana Grunow	5	3,700
Nitzschia palea (Kützing) W. Smith	1	740
Nitzschia paleacea Grunow	10	7,400

Algal Identification and Quantification Data Sheet

USGS station name: Gum Bayou at Farm Road 517 near Texas City - Page 3 of 3
USGS station number: 08077649
Date collected: 9/8/95

Taxa	**No. of cells counted**	**Cells/cm^2**
Nitzschia panduriformis var. *delicatula* Grunow	3	2,220
Nitzschia pseudofonticola Hustedt	3	2,220
Nitzschia pusilla Grunow	1	740
Nitzschia romana Grunow	1	740
Nitzschia sigma (Kützing) W. Smith	4	2,960
Nitzschia siliqua Archibald	5	3,700
Nitzschia sp. 1 VA	13	9,620
Nitzschia sp. 10 VA	13	9,620
Nitzschia sp. 11 VA	2	1,480
Nitzschia tryblionella var. *salinarum* Grunow	1	740
Pleurosigma salinarum Grunow	1	740
Rhopalodia gibberula (Ehrenberg) O. Müller	2	1,480
Rhopalodia gibberula var. *vanheurckii* O. Müller	2	1,480
Rhopalodia musculus (Kützing) O. Müller	1	740
Rhopalodia sp. 1 VA	4	2,960
Surirella Turpin sp.	1	5,270
Surirella inducta Hustedt	4	2,960
Tabularia fasciculata (Kützing) Williams & Round	1	740
Tryblionella levidensis W. Smith	1	740
Tryblionella littoralis (Grunow in Cleve & Grunow) D.G. Mann	2	1,480
diatom spp.	9	47,400
cryptomonads	1	5,270
Anacystis montana (Lightfoot) Drouet & Dailey	1	5,270
Calothrix parietina (Nägeli ex Kützing) Thuret	235	1,240,000
Lyngbya lagerheimii (Möbuis) Gomont	224	1,180,000
Schizothrix calcicola (Agardh) Gomont	78	411,000