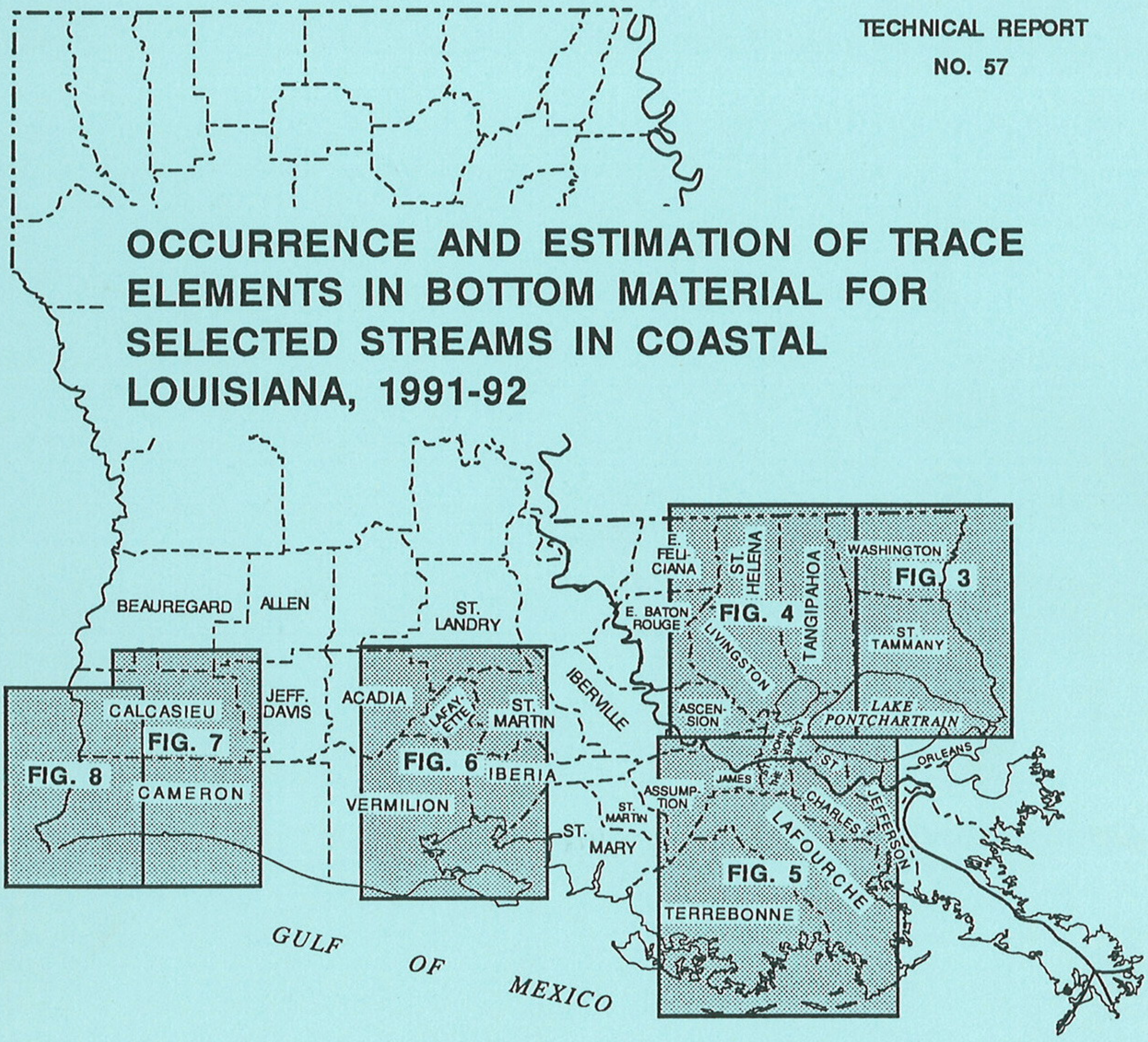
STATE OF LOUISIANA
DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT
PUBLIC WORKS AND FLOOD CONTROL DIRECTORATE
WATER RESOURCES SECTION

WATER RESOURCES

TECHNICAL REPORT

NO. 57

OCCURRENCE AND ESTIMATION OF TRACE ELEMENTS IN BOTTOM MATERIAL FOR SELECTED STREAMS IN COASTAL LOUISIANA, 1991-92



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CONVERSION FACTORS, ABBREVIATED WATER-QUALITY UNITS, AND DISCLAIMER

Multiply	By	To obtain
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows: °F =1.8°C+32.

Abbreviated water-quality units:

liter (L)

meter (m)

square meter per gram (m^2/g)

micrometer (µm)

milligrams per kilogram (mg/kg)

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OCCURRENCE AND ESTIMATION OF TRACE ELEMENTS IN BOTTOM MATERIAL FOR SELECTED STREAMS IN COASTAL LOUISIANA, 1991-92

By Benton D. McGee *and* Dennis K. Demcheck

ABSTRACT

Six streams (Pearl River, Tickfaw River, Bayou Lafourche, Vermilion River, Calcasieu River, and Sabine River) in six basins in coastal Louisiana were sampled for trace elements in bottom material during 1991-92. Bottom material samples were collected and analyzed to determine concentrations of the following trace elements: antimony, arsenic, chromium, cobalt, copper, lead, mercury, nickel, selenium, and zinc. The minimum and maximum concentrations, in milligrams per kilogram, of each trace element and the stream in which they were detected are as follows: Antimony, less than 0.1 (Pearl River) and 1 (Bayou Lafourche); arsenic, 0.3 (Tickfaw River) and 16 (Bayou Lafourche); chromium, 1 (Pearl River and Tickfaw River) and 71 (Bayou Lafourche); cobalt, 2 (Pearl River and Tickfaw River) and 15 (Bayou Lafourche); copper, less than 1 (Pearl River) and 53 (Bayou Lafourche); lead, less than 1 (Sabine River) and 67 (Calcasieu River); mercury, less than 0.01 (Pearl River) and 0.47 (Calcasieu River); nickel, less than 1 (Sabine River) and 38 (Bayou Lafourche); selenium, less than 0.1 (Pearl River and Sabine River) and 0.9 (Bayou Lafourche); and zinc, 1 (Tickfaw River) and 208 (Bayou Lafourche).

In addition, the bottom-material samples were analyzed to determine physical and chemical properties that affect trace-element concentrations: grain size, surface area, organic matter, and iron and manganese oxide coatings. Mean grain size typically decreased and organic matter increased in a downstream direction. Each site, however, had a unique set of physical and chemical factors affecting the distribution of trace elements.

The trace-element concentrations measured in bottom material from the streams were compared to effects range-low (ER-L) and effects range-median (ER-M) threshold concentrations. The ER-L and ER-M values represent 10th and 50th percentile concentrations that, when exceeded, may produce adverse reactions in biota. Concentrations below the ER-L indicate a minimal adverse effects range. Concentrations between the ER-L and ER-M indicate a possible adverse effects range, and concentrations above the ER-M indicate a frequent adverse effects range. No sample had trace-element concentrations that exceeded the ER-M; however, the ER-L was exceeded in four streams. The streams having concentrations of trace elements that exceeded the ER-L were Bayou Lafourche (lead, mercury, nickel, and zinc); the Vermilion River (lead and nickel); the Calcasieu River (lead, mercury, and nickel); and the Sabine River (lead). The Pearl River and Tickfaw River had no sites with trace-element concentrations that exceeded the ER-L values.

Multiple linear regression equations were used to estimate background (naturally occurring) concentrations for trace elements based on the physical and chemical properties of the bottom-material samples. These estimated background concentrations were compared to the measured data. Sampling sites where measured trace-element concentrations exceeded by 20 percent the estimated concentration, and the comparison was considered statistically valid, were identified as having elevated concentrations of trace elements. Concentrations of five trace elements (copper, lead, mercury, nickel, and selenium) exceeded estimates on the Calcasieu River; five (arsenic, copper, lead, mercury, and zinc) on Bayou Lafourche; four (arsenic, copper, lead, and zinc) on the Vermilion River and Sabine River; one (nickel) on the Pearl River; and none on the Tickfaw River. The groupings may represent a ranking of the relative amount of adverse effects of trace elements on these streams.

INTRODUCTION

Bottom material in surface water generally is recognized as a long-term integrator of water quality at a site. According to Horowitz (1991, p. 12), trace elements associated with bottom material may record a chemical history of an aquatic system through time. This chemical history allows us to determine background trace-element concentrations within the system. Background trace-element concentrations are defined as the trace-element concentrations that occur naturally within aquatic systems as a result of the physical and chemical interactions between native sediments and streams. These background concentrations can be compared to current trace-element concentrations to identify sites affected by anthropogenic sources.

Current trace-element data for bottom material, needed for assessment of coastal Louisiana streams, are not available. The data that are available lack key physical and chemical analyses that are crucial in identifying anthropogenic origins of these elements in the aquatic environment. Based on the results from a previous study by Demcheck (1994), accurate data on the physical properties and chemical composition of bed sediments from this region, used in conjunction with sediment-trace element models, can be used to identify sites with elevated concentrations of trace elements. In an effort to further understand the role of trace elements in the aquatic environment, the U.S. Geological Survey (USGS), in cooperation with the Louisiana Department of Transportation and Development (DOTD), began a study in 1991 to investigate trace-element concentrations associated with bottom material in selected streams in Louisiana. The objectives of the study were to (1) determine concentrations of selected trace elements in bottom material from potentially affected streams in coastal Louisiana, (2) document the physical and chemical properties that affect the occurrence of these trace elements in the aquatic environment, and (3) evaluate local sediment-trace element predictive models to identify potentially affected sites and sites with elevated trace-element concentrations for further evaluation.

Background trace-element concentrations can be estimated using statistical methods. Multiple linear regression equations have, in the past, explained a relatively high percentage of measured sediment-trace-element concentrations (Horowitz and others, 1989). These equations are derived using available chemical and physical sediment data collected from sites presumed to be relatively unaffected by human activities. Using these equations to estimate background trace-element concentrations can help to identify sites that are chemically affected by anthropogenic sources and provide insight into the physical and chemical properties affecting trace-element distributions in sediments.

Bottom material from streams in coastal Louisiana generally exhibits a decrease in grain size southward as the stream approaches the coast. Coastal marsh sediments tend to contain higher amounts of organic matter than sediments in other regions, due to the high rate of decomposition of marsh plants. Also, water chemistry and land use may differ with each basin and from site to site within a basin. These differences affect the distribution of trace elements in the stream by creating favorable or unfavorable conditions for the adsorption of trace elements onto bottom material. Therefore, it is important to document the physical and chemical properties that make each basin unique. Due to the unique physical and chemical nature of each basin, interbasin comparisons of trace-element concentrations would require careful consideration of these properties.

Purpose and Scope

This report describes the measured (chemically analyzed) and estimated background trace-element concentrations in bottom material from six streams (Pearl River, Tickfaw River, Bayou Lafourche, Vermilion River, Calcasieu River, and Sabine River) in coastal Louisiana (fig. 1). The report also identifies reaches of the streams in which trace-element concentrations were significantly elevated above estimated background concentrations.

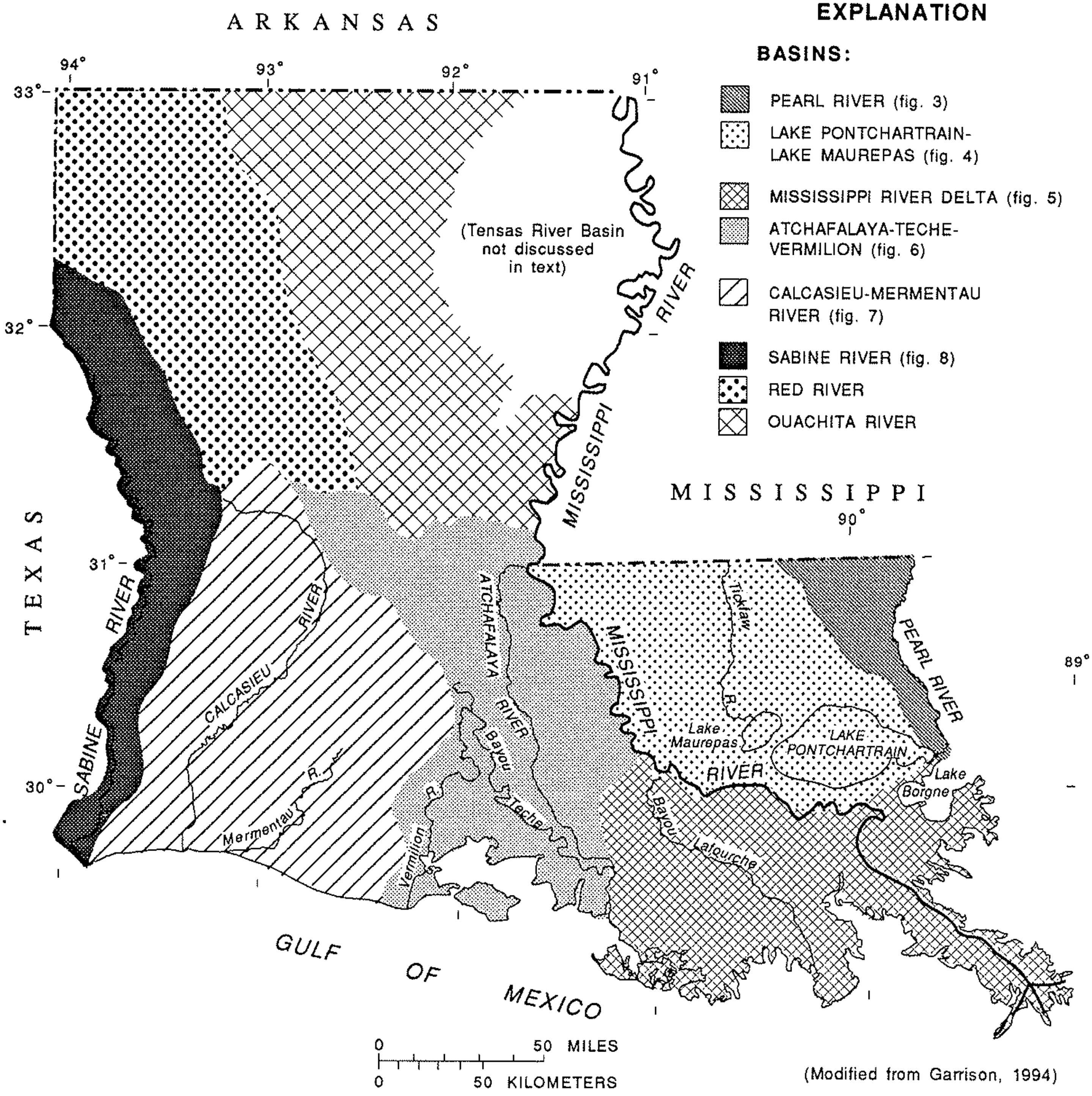
During 1991-92, 55 sediment samples were collected from bottom material in six streams; 9 samples each were collected from five streams, and 10 were collected from the Calcasieu River. The trace-element concentrations in bottom material are affected by the regional land use within each river basin; therefore, the study area in this report includes the six respective river basins (Pearl River, Lake Pontchartrain-Lake Maurepas, Mississippi River Delta, Atchafalaya-Teche-Vermilion, Calcasieu-Mermentau River, and Sabine River) within which the selected streams are located (fig. 1) (Garrison, 1994).

Description of Study Area

The study area consists of six streams within six respective basins that are located mostly in southern Louisiana (fig. 1): Pearl River (Pearl River Basin); Tickfaw River (Lake Pontchartrain-Lake Maurepas Basin), Bayou Lafourche (Mississippi River Delta Basin), Vermilion River (Atchafalaya-Teche-Vermilion Basin), Calcasieu River (Calcasieu-Mermentau River Basin), and Sabine River (Sabine River Basin) (Garrison, 1994). The area of primary interest is in and near coastal Louisiana and includes the reaches of the six streams that contain fine-grained, organic enriched sediments.

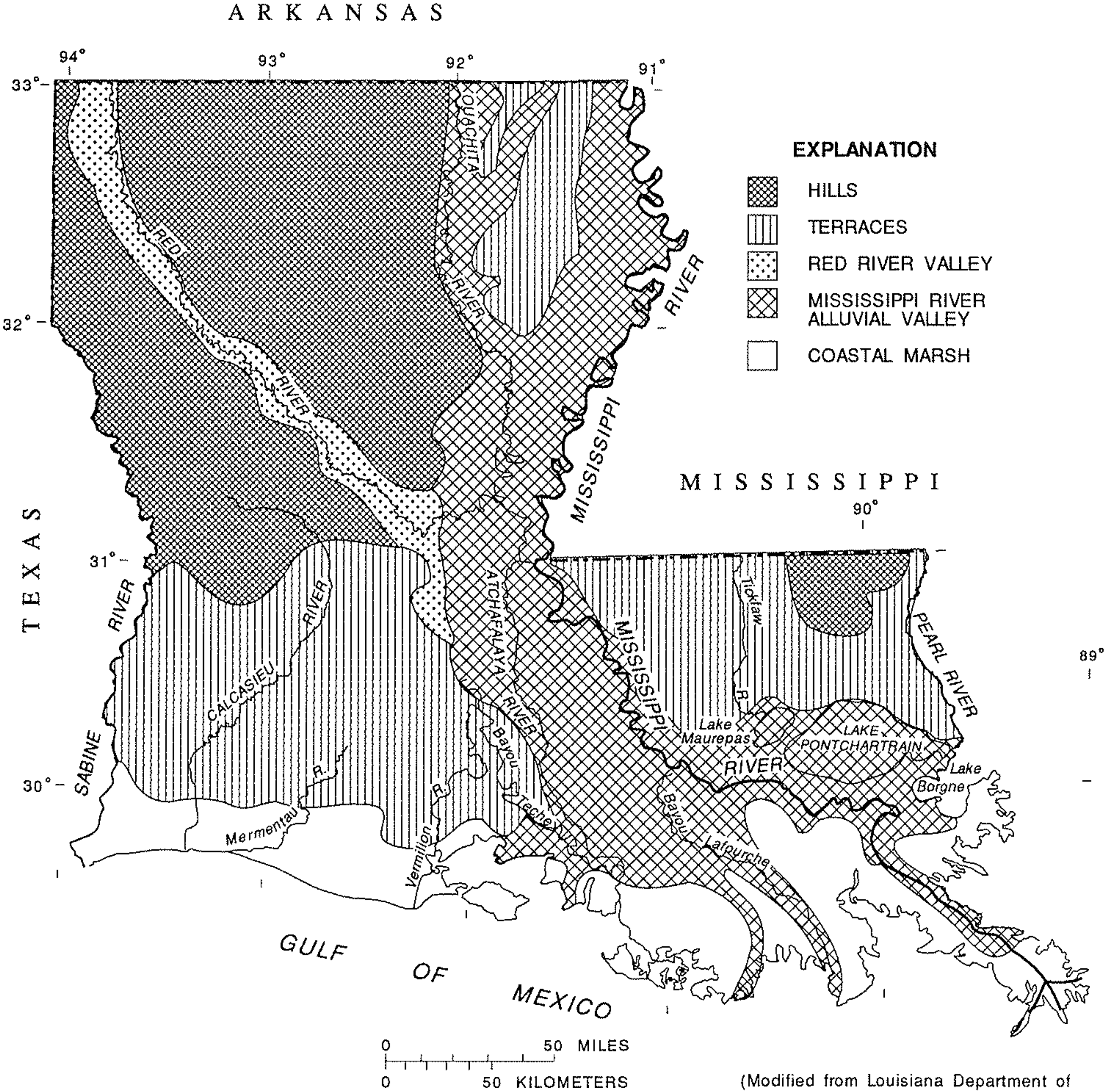
The study area is located within the Coastal Plain physiographic province, which, in coastal Louisiana, comprises five natural regions (fig. 2): hills, terraces, coastal marsh, Red River Valley, and Mississippi River alluvial valley (Louisiana Department of Environmental Quality, 1990, p. 4). Physical and chemical properties of bottom material in these regions vary. For example, the Mississippi River alluvial valley has a high percentage of fine-grained minerals and organic matter, whereas upland areas such as the Lake Pontchartrain-Lake Maurepas Basin are composed of a larger percentage of coarse-grained minerals with a lower percentage of organic matter.

Upland hills and terraces make up the Pearl River Basin in Louisiana (fig. 2). The northern area of the basin is characterized by high elevations and steep slopes. The southeastern area has flat terraces with gradual transitions to the broad, flat-bottomed lower valleys. In the southern area, the Pearl River becomes a braided stream comprising many interconnected channels (fig. 3). The extreme southern reach of the river is estuarine. In Louisiana, the basin is bounded to the north by the Louisiana-Mississippi State line, to the east by the river itself, to the south by Lake Borgne, and to the west by the Lake Pontchartrain-Lake Maurepas Basin (fig. 1). Although the Pearl River Basin is primarily forested, about one-fifth of the basin is



(Modified from Garrison, 1994)

Figure 1. Selected streams and basins in Louisiana.



(Modified from Louisiana Department of Transportation and Development, 1984)

Figure 2. Natural regions in Louisiana.

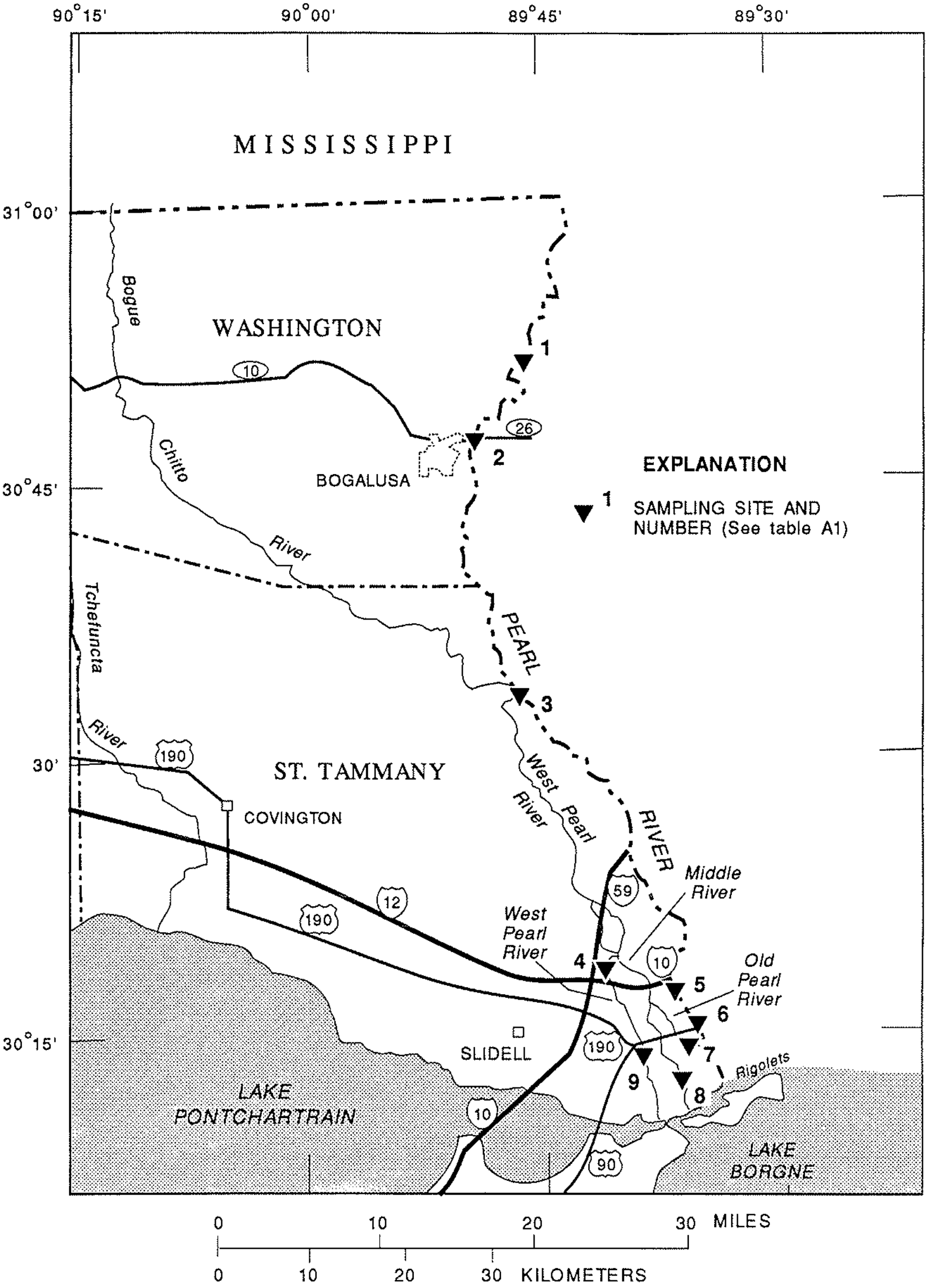


Figure 3. Study area and sampling sites in the Pearl River (Pearl River Basin).

made up of pasture and cropland scattered within the forest lands (Louisiana Department of Transportation and Development, 1984). Forested wetlands occupy most of the valley areas of the basin. The Pearl River Basin has extensive marshes that generally are located south of Interstate Highway 10 (I-10). Urbanization in the basin is confined mainly to the areas in and around Bogalusa and Slidell (fig. 3).

The Tickfaw River is in the Lake Pontchartrain-Lake Maurepas Basin (fig. 1), within the upland terraces of Louisiana except for a small part within the Mississippi River alluvial valley (fig. 2). The northern part of the river flows through upland terraces to the flat-bottomed valleys characteristic of the southern reaches of the river. In Louisiana, the basin is bounded to the north by the Louisiana-Mississippi State line, to the east by the Pearl River Basin, to the south by the Mississippi River Delta Basin, and to the west by the Atchafalaya-Teche-Vermilion Basin (fig. 1). The Tickfaw River begins in southern Mississippi and flows south through St. Helena and Livingston Parishes in Louisiana before it empties into Lake Maurepas (fig. 4). The basin includes several small towns and fishing camps along its length in Louisiana, but is mostly composed of forest land.

Bayou Lafourche is within the Mississippi River Delta Basin (fig. 1) and is within the Mississippi River alluvial valley and coastal marsh natural regions of the State (fig. 2). The bayou begins at Donaldsonville and generally is oriented northwest to southeast (fig. 5). Several thousand years ago, Bayou Lafourche was the main channel of the Mississippi River. As the course of the river shifted, Bayou Lafourche remained a distributary until 1902, when the Mississippi River-Bayou Lafourche connection was closed off. The natural levees deposited by the Mississippi River produced a fertile strip of land higher than the surrounding marshes, which were intensively farmed and developed (Conner and Day, 1987, p. 1). The Mississippi River Delta Basin is bounded by the Lake Pontchartrain-Lake Maurepas Basin to the north, the Louisiana-Mississippi State line and the Pearl River Basin to the east, the Gulf of Mexico to the south, and the Atchafalaya-Teche-Vermilion Basin to the west (fig. 1). The basin is composed largely of wooded lowlands, and marshes that have fresh, brackish, and saline waters. Marshes and wetland forests cover most of the basin but have been substantially reduced by urbanization and conversion of marshes to open water in coastal areas (Louisiana Department of Transportation and Development, 1984, p. 281).

The Vermilion River is within the Atchafalaya-Teche-Vermilion Basin (fig. 1). The river can be separated into two distinct reaches, the upper and lower Vermilion River. The upper Vermilion River is about 28 mi long and extends to the southern part of the City of Lafayette (fig. 6). The upper river has a broad valley, and its banks are only slightly higher than the adjacent lands. The lower Vermilion River, about 33 mi long, begins downstream from Lafayette and flows into Vermilion Bay. The lower river has high banks and a well-defined stream valley. The flow of the Vermilion River, from Lafayette downstream, is affected by tidal fluctuations at all stages (Demcheck and Leone, 1983, p. 2). The basin is bounded by the Red and Ouachita River Basins to the north, Lake Pontchartrain-Lake Maurepas Basin and Mississippi River Delta Basin to the east, the Gulf of Mexico to the south, and the Calcasieu-Mermentau River Basin to the west (fig. 1). Most of the basin is composed of flat-lying and hilly terrace lands, and the southern part of the basin is made up of coastal marshes (fig. 2).

The Calcasieu-Mermentau River Basin (fig. 1) is mainly within flat to slightly sloping terraces (fig. 2). The Calcasieu-Mermentau River Basin is bounded in Louisiana to the north by the Red River and Atchafalaya-Teche-Vermilion Basins, to the east by the Atchafalaya-Teche-Vermilion Basin, to the south by the Gulf of Mexico, and to the west by the Sabine River Basin (fig. 1). The northern reaches of the basin are mostly oak-pine forests. The central part is primarily prairie land and is a major rice-producing area. The southern part is a mixture of prairie and fresh to brackish marshes. The City of Lake Charles (fig. 7) is the primary urban and industrial area within the basin.

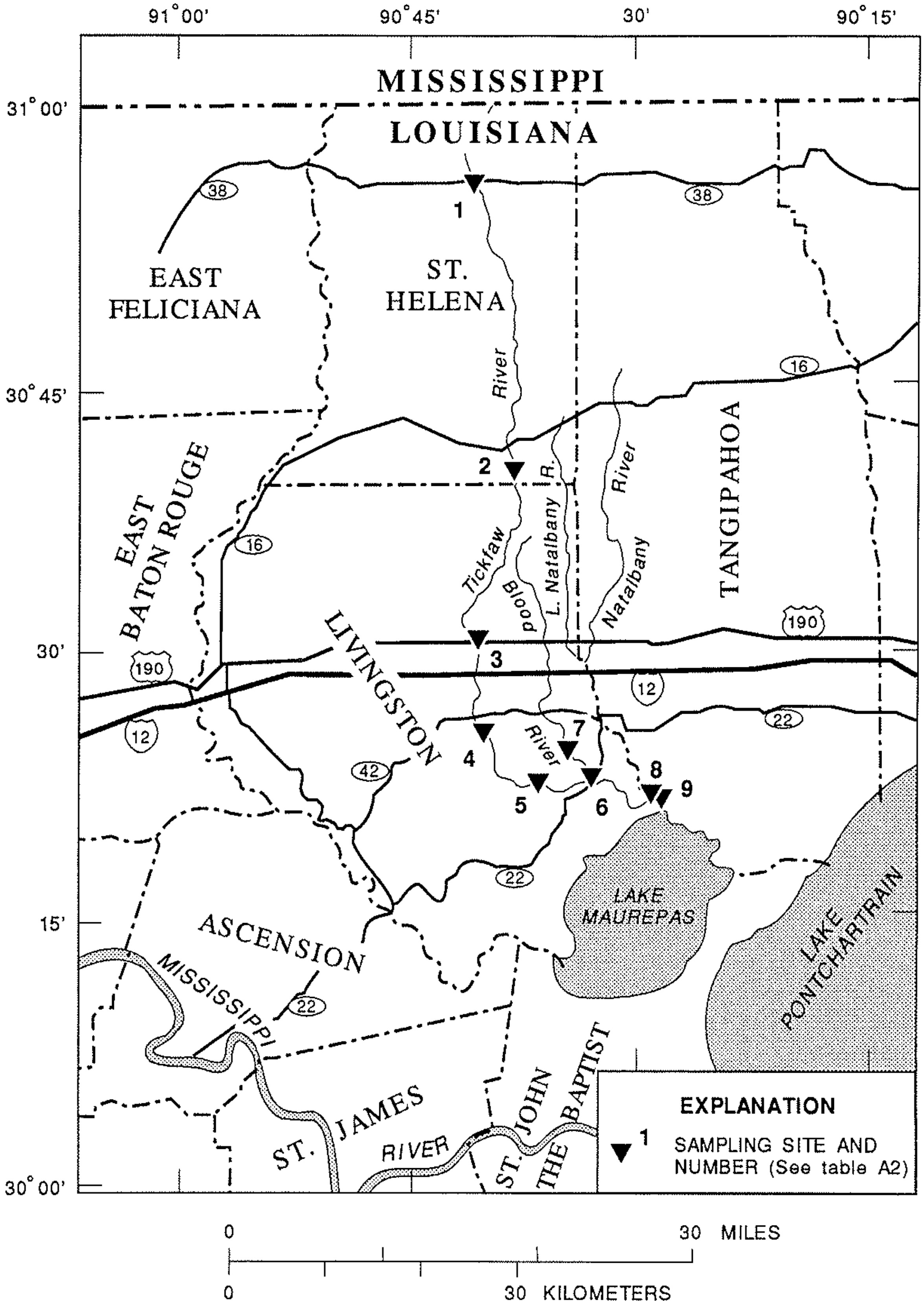


Figure 4. Study area and sampling sites in the Tickfaw River (Lake Pontchartrain-Lake Maurepas Basin).

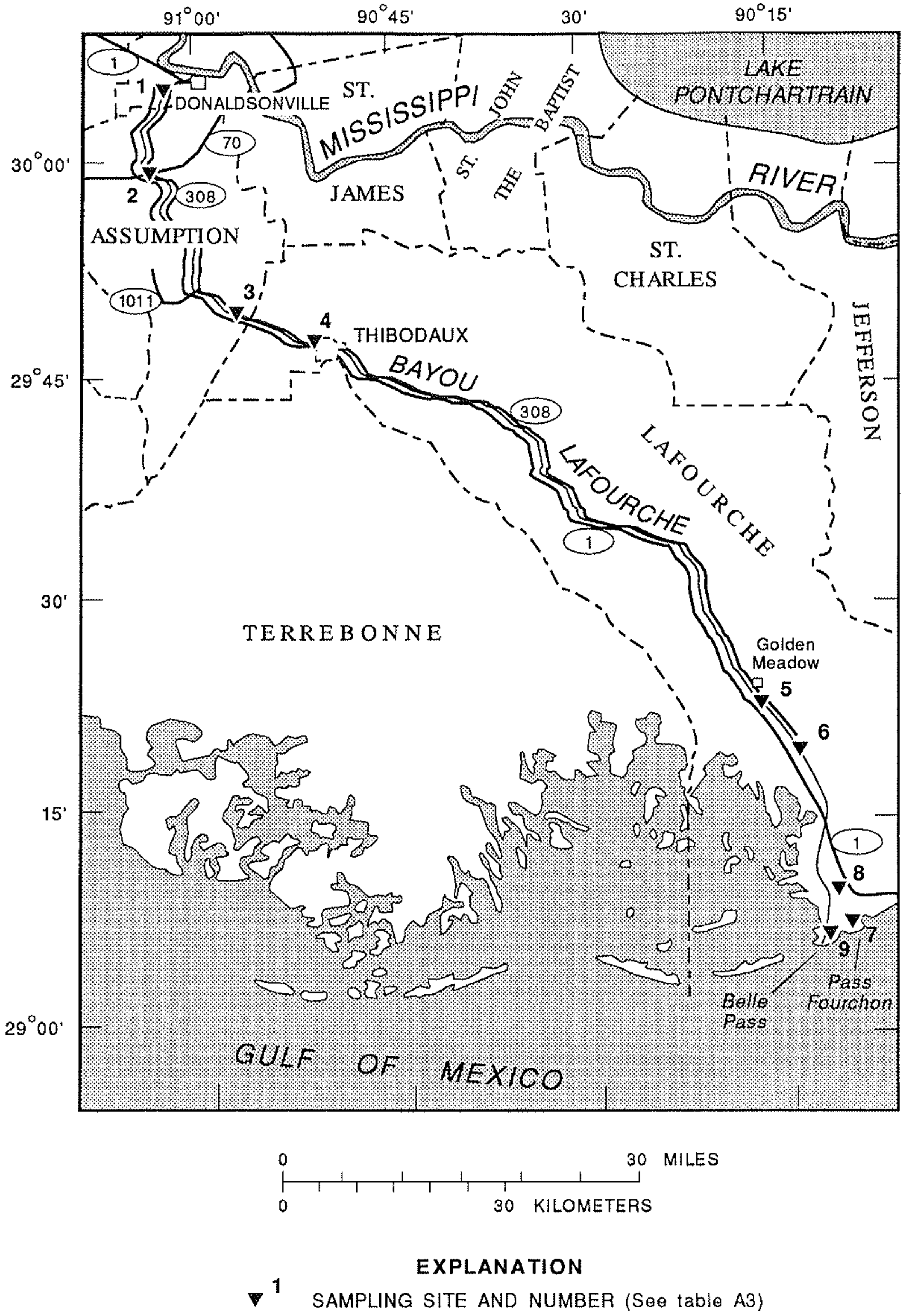


Figure 5. Study area and sampling sites in Bayou Lafourche (Mississippi River Delta Basin).

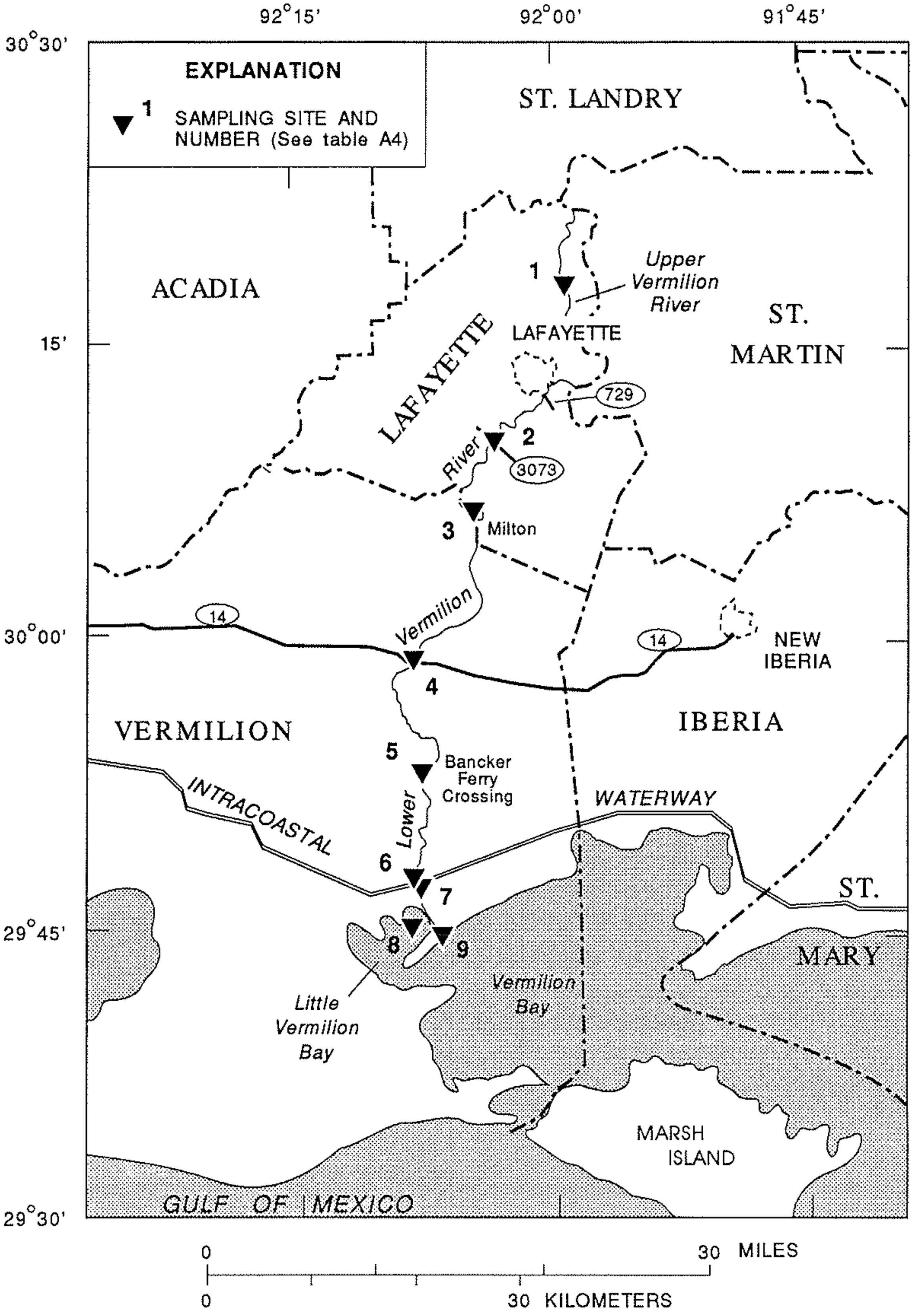


Figure 6. Study area and sampling sites in the Vermilion River (Atchafalaya-Teche-Vermilion Basin).

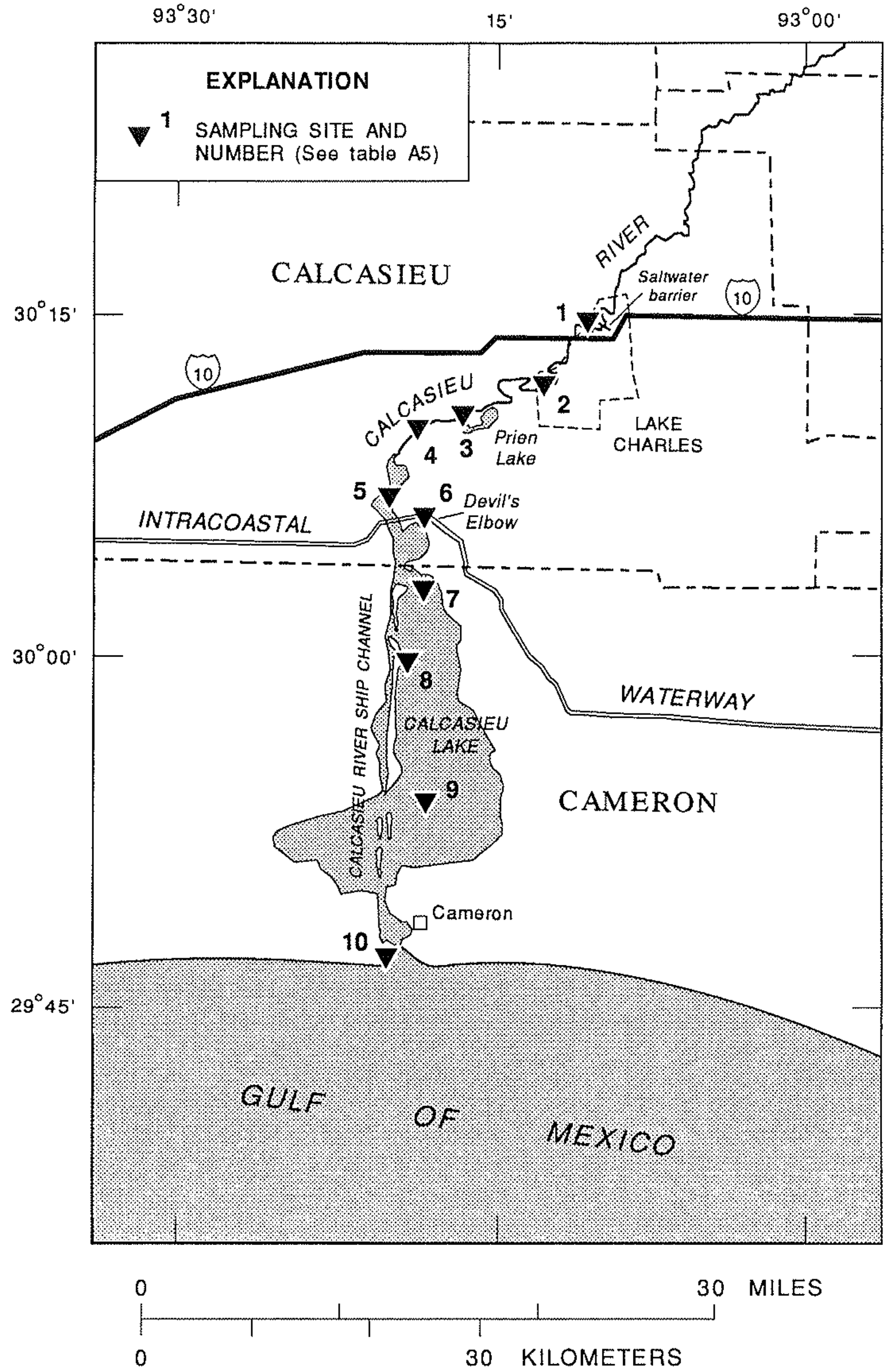


Figure 7. Study area and sampling sites in the Calcasieu River (Calcasieu-Mermentau River Basin).

The Calcasieu River reach included in this study extends about 42 river miles from the Gulf of Mexico to just upstream of a saltwater barrier. The barrier is a gated structure designed to protect freshwater swamps in the area from saltwater intrusion. The Calcasieu River north of Lake Charles is bordered primarily by oak-pine forests. The central part of the stream reach, at and extending about 10 mi south of Lake Charles, is bordered by a cluster of petrochemical and agrichemical industries. The southern part of the river is used extensively for navigation and commercial fisheries.

The Sabine River Basin is mainly within the hills, terraces, and the coastal marsh regions (fig. 2). The hills are surface outcrops of relatively old sediment. The terraces are flat-lying and have eroded along streams to create a rolling landscape. The coastal marsh is a low coastal plain composed of deltaic deposits. The basin extends 190 mi north from the gulf coast and is 25 mi wide at its widest (Louisiana Department of Transportation and Development, 1984). In Louisiana, the basin is bounded on the northeast by the Red River Basin, on the southeast by the Calcasieu-Mermentau River Basin, on the south by the Gulf of Mexico, and on the west by the Louisiana-Texas State line (fig. 1). The northern part of the basin is primarily forestland, consisting of pines in the upland areas and mixed forests along streams; the southern part of the basin is primarily estuarine. Accordingly, farmland and land uses associated with agriculture are mostly in the northern part of the basin, and petrochemical industries, fishing, and navigation are mostly in the southern part of the basin. There is very little urbanization within the basin, with the exception of the cities of Port Arthur, Tex., and Orange, Tex. (fig. 8), which support large petrochemical and fishing industries. The Sabine River reach studied extends about 35 river miles from the Gulf of Mexico, through Sabine Lake, to Old River. Old River is a tributary to the Sabine River.

Previous Studies

Trace-element concentrations in bottom material have been investigated in many studies. In a study by the National Oceanic and Atmospheric Administration (Long and Morgan, 1990), samples containing sediment-sorbed contaminants, including trace elements, were collected in coastal river and estuary environments throughout the United States. The report describes the potential for adverse biological effects due to exposure of biota to contaminated bottom material.

In that study (Long and Morgan 1990), effects range-low (ER-L) and effects range-median (ER-M) threshold concentrations were developed for some trace elements because no standards had been established. An ER-L value was defined as the concentration associated with the 10th percentile of the effects data for a compound, and ER-M value was defined as the concentration associated with the 50th percentile of effects data. Concentrations below the ER-L are expected to indicate conditions under which adverse biological effects would rarely occur (a minimal effects range). Concentrations between the ER-L and ER-M value fall in a possible effects range, in which adverse biological effects would occasionally be observed. Concentrations above the ER-M represent a probable effects range, where negative effects would be expected to occur frequently. ER-L and ER-M concentrations (in milligrams per kilogram) for 8 of the 10 bottom-material trace elements sampled for this study are as follows: antimony, 2 and 25; arsenic, 33 and 85; chromium, 80 and 145; copper, 70 and 390; lead, 35 and 110; mercury, 0.15 and 1.3; nickel, 30 and 50; and zinc, 170 and 270, respectively.

Horowitz and others (1989) conducted a study of trace elements in bottom material, using 61 samples collected throughout the United States. Using multiple linear regression equations calculated from physical and chemical bottom-material properties such as grain size, percent organic matter, and oxide coatings, the study explained at least 70 percent of the observed sediment-trace-element variance for 10 trace elements.

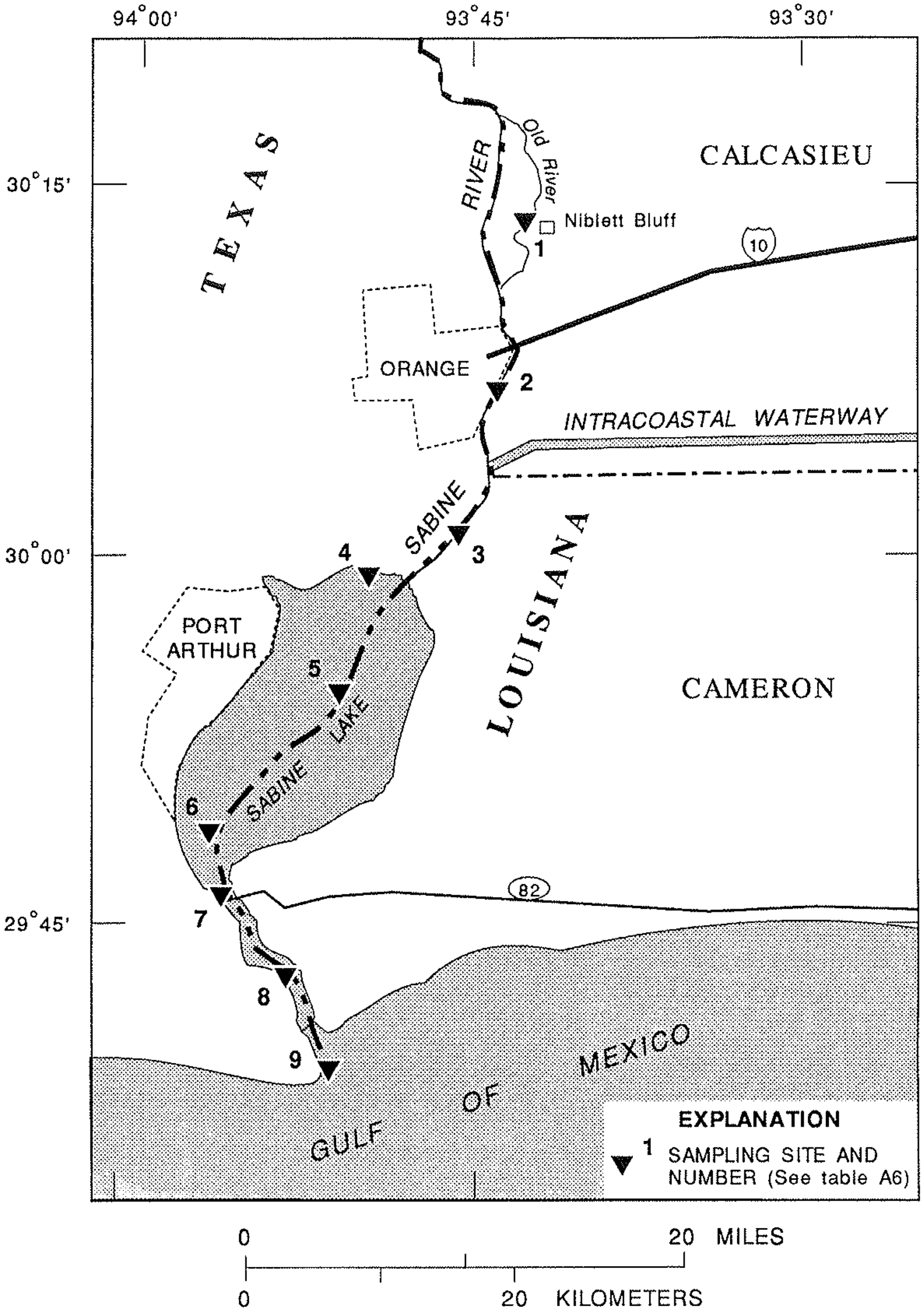


Figure 8. Study area and sampling sites in the Sabine River (Sabine River Basin).

Demcheck (1994) related trace-element concentrations to physical and chemical properties of bottom material in the Mermentau River. The resulting trace-element equations identified the causes of elevated trace-element concentrations at 13 sampling sites.

Simon (1988) identified four mechanisms for retention of chromium by bottom material in the Calcasieu River. Chromium was shown to be partitioned in iron-oxide phases, manganese-oxide phases, labile organic matter, and refractory organic matter.

Acknowledgments

The authors extend appreciation to Zahir "Bo" Bolourchi, Chief of the Water Resources Section, Louisiana Department of Transportation and Development, whose valuable advice and suggestions enhanced the quality of this report.

METHODS

Most of the sampling sites were located in the lower reaches of each stream that contained fine-grained sediments and naturally occurring organic detritus. Samples were collected during periods of low and moderate flow, from both boats and bridges, depending upon the accessibility of the stream.

All bottom-material samples were collected with a nylon-coated Petite Ponar sediment sampler. This sampler has a 6-in. square grab that penetrates about 4 in. into the substrate. The screened top of the sampler allows water to escape as the sampler is lowered, producing minimal disturbance of the surficial layer of bottom material. To ensure the collection of a representative sample, five 1-L samples were collected at each site and composited. Three samples were collected in a cross-section of the stream: One was taken at the approximate midpoint of the stream channel, and one each at the extreme left and right of the stream channel as depth permitted. The remaining two samples were collected approximately one channel-width upstream and downstream from the midpoint of the cross-section. The samples were composited using a clear-plastic container and a wooden spoon to avoid sample contamination. The container, ponar, and spoon were thoroughly cleaned between sample collections. A 1-L subsample was collected from the 5-L composite. The subsamples were kept at 4 °C after collection, then shipped frozen to a USGS laboratory for analysis of trace elements. During sample collection, specific conductance, pH, temperature, dissolved oxygen (DO), and depth were measured. These measurements were made about 1.5 ft below the stream surface and 1.5 ft above the stream bed in streams deeper than 3 ft. In shallower streams, measurements were made at mid-depth.

At the laboratory, samples were sieved through a 2,000-μm plastic screen and freeze-dried. Two large aliquots were taken from each sample. The first aliquot was ground (if necessary) to less than 100 μm and used for bulk chemical analysis. The second aliquot was used for determination of grain-size distribution, surface area measurements, and the determination of selected oxide coatings.

The chemical analyses for the trace elements examined in this report were performed using atomic absorption spectroscopy. Procedures describing the chemical analysis, substrate determinations, and physical measurements are detailed by Horowitz and others (1989).

EFFECTS OF PHYSICAL AND CHEMICAL PROPERTIES ON OCCURRENCE OF TRACE ELEMENTS

Physical and chemical properties can be quantified to better understand sediment-trace-element chemistry. Physical properties that affect the distribution of trace elements include grain size and surface area. Chemical properties that affect the distribution of trace elements include dissolved oxygen, pH, total organic carbon, manganese oxides, iron oxides, and the interaction between trace elements and sediment, such as complexation and substitution.

Bottom Material

One of the most important physical properties controlling trace-element concentrations is sediment grain size. There is a direct relation between decreasing sediment grain size and increasing trace-element concentration. Fine-grained sediments, because of their large surface areas, are the primary sites of accumulation and transport of trace elements. Although trace elements also accumulate on substrates such as sand and pebbles, high concentrations are, in general, associated with fine-grained sediments.

Typically, coastal-marsh sediment in Louisiana is high in organic matter and exhibits a decreasing average grain size towards the Gulf of Mexico. The combination of increasing organic-matter content and decreasing grain size causes the potential for high background trace-element concentrations to exist naturally in these bottom materials. Conversely, bottom material that exhibits large grain sizes, resulting in small surface areas and a low organic-matter content, has less potential for high background trace-element concentrations by comparison (Horowitz, 1991).

Due to adsorption, trace elements tend to accumulate on the surface of particles; therefore, materials having large surface areas are good sites for trace-element accumulation, or good adsorbers. Furthermore, deposited materials such as organic matter, hydrous iron, and manganese oxides may act as additional adsorbers. As surface area increases due to the addition of deposited material, the amount of these adsorbers also increases, thus the element-concentrating capacity of the surface is compounded.

Two approaches commonly are used in the evaluation of chemical partitioning: mechanistic and phase. The purpose of the mechanistic approach is to determine how trace elements are retained on or by sediments. Major mechanisms for trace-element accumulation on suspended sediment and bottom material include adsorption, precipitation, organometallic bonding, and cation exchange. The phase approach seeks to determine where inorganic constituents are located on sediments. Individual constituents (such as cobalt, copper, lead, nickel, zinc, iron, and manganese) may be associated with phases such as interstitial water, clay minerals, sulfides, carbonates, humic acids, and iron and manganese oxides. Few attempts to chemically partition complex sediment samples involve a strictly mechanistic or phase approach; more commonly, they combine aspects of both (Horowitz, 1985, p. 36).

Cation exchange is the process by which a material adsorbs cations from solution and releases equal amounts (on an equivalent-weight basis) of other cations back into solution. Most trace elements are cations (have a positive ionic charge), and the surfaces of most materials that can conduct cation exchange have a net negative charge. The measurement of a material's ability to sorb cations is called cation exchange capacity (CEC). The CEC results from the availability of negatively charged sites on the sediment particles. As grain size decreases and surface area increases, the CEC increases.

Historically, clay minerals were thought to act as substantial adsorbers and concentrators of trace elements in aquatic environments. It was believed that broken chemical bonds around the edges of the clay mineral determined the mineral's CEC. Studies have indicated, however, that clay minerals do not actually collect and concentrate the trace elements; rather, the clay minerals act as a physical substrate for the precipitation and flocculation of organic matter and secondary minerals, such as hydrous iron and iron and manganese oxides, on which trace elements can collect and concentrate (Horowitz, 1985, p. 28).

Iron and manganese oxides are known to form coatings on clay-sized particles and provide sites for adsorption of trace elements from solution. In both suspended sediment and bottom material, iron and manganese oxides commonly occur on minerals and particles as nodules and coatings. Forms of these nodules or coatings range from amorphous to microcrystalline to crystalline (Horowitz, 1985). Regardless of the form, hydrous iron and iron and manganese oxides are substantial collectors of trace elements in aquatic systems.

Water

The distribution of trace elements in an aquatic environment is influenced by physical and chemical properties; however, water quality also influences the distribution and concentration of trace elements associated with bottom material. Four on-site water-quality measurements (temperature, pH, DO, and specific conductance) were made at each site at the time of the bottom-material sample collection (app. A, tables A1 to A6). These data can aid in understanding the trace-element distributions in bottom material.

Trace-element concentrations in bottom material are substantially influenced by pH. Forstner and Wittmann (1981) have shown that most freshwater has a specific range of pH that is critical for adsorption of trace elements onto particulates. As little as one pH unit can determine if a trace element is to be adsorbed or desorbed. In general, as pH increases, the availability of trace elements for adsorption increases. This increase in adsorption translates to increased amounts of trace elements available for association with bottom material. As pH decreases, trace elements are desorbed, resulting in a decrease in bottom-material-associated trace elements.

Dissolved oxygen affects trace-element distributions and concentrations by enabling manganese and iron oxides to form on the surface of sediments, providing a favorable substrate onto which trace elements may be adsorbed. Consequently, if dissolved oxygen concentrations remain high, and other water-quality properties are unchanged, trace elements tend to remain associated with bottom material.

Increases in the ionic strength of the water column, approximated in this report by increases in specific conductance, can cause organic matter and associated trace elements to precipitate out of solution. Because of the high CEC of organic matter, trace elements will readily adsorb onto organic matter. The concentration of trace elements in bottom material is increased as organic matter precipitates from the water column, stripping trace elements from solution as the precipitate settles to the bottom. In coastal Louisiana streams, a zone of increased trace-element concentrations in bottom material commonly occurs in areas where higher ionic-strength water from the Gulf of Mexico mixes with river water. The mixing zone may be restricted to a short reach of a stream or be long and variable, depending on stream discharge, season, or amplitude of the tides.

ESTIMATION OF TRACE-ELEMENT CONCENTRATIONS IN BOTTOM MATERIAL BASED ON PHYSICAL AND CHEMICAL PROPERTIES

Bottom material has the capacity to retain and concentrate trace elements based upon its physical and chemical characteristics. Multiple linear regression equations calculated from chemical properties have, in the past, explained a high percentage of the measured trace-element data (Horowitz and others, 1989, p. 347). An analysis of both physical and chemical properties provides a means of estimating the background trace-element concentrations for a particular stream or site. If the background trace-element concentrations can be estimated, then streams or sites which have elevated trace-element concentrations also may be identified.

This section describes the process by which the trace-element estimation equations were generated. The sites sampled were selected after examining historical USGS data to avoid grossly contaminated areas; however, as all Louisiana streams are utilized to some extent for recreational, industrial, agricultural, or commercial purposes, no site can be termed completely unaffected.

The calculations necessary to analyze the bottom-material data and generate the trace-element estimation equations were performed using a statistical analysis program for microcomputers called Statview II (Horowitz and others, 1989, p. 351). Statview II uses a stepwise regression to generate the estimation equations for the trace elements in this study.

Using a stepwise regression, the entry of every new independent variable triggers a reevaluation of all previous variables. If subsequent entries could account for the new variable's variance contribution, that variable could be removed from the equation. The equation's performance was measured using the r^2 statistic, which takes the number of parameters and sample size into account. The number of independent variables within each equation was limited to four or less, although the stepwise regression analysis often indicated that more than six independent variables could be added to an equation. The addition of more than four independent variables did little to improve the correlation coefficient, *r*. Detailed information pertaining to the statistical methods used to derive the bottom-material trace-element estimation equations are discussed by Horowitz and others (1989).

To measure how closely the equations estimated the measured trace-element concentrations, correlation coefficients, *r*, are calculated for the estimated and measured trace-element concentrations. The final trace-element estimation equations used for all six basins and their correlation coefficients are listed below:

$$\begin{gathered}\mathrm{Sb} = 0.448 \times \mathrm{Ti} + 0.192 \times \mathrm{Ex.Mn} - 0.163 \times Mz - 0.290 \\ r = 0.94;\end{gathered} \tag{1}$$

$$\begin{gathered}\mathrm{As} = 0.755 \times \mathrm{Fe} + 0.191 \times \mathrm{Mn} + 0.743 \\ r = 0.96;\end{gathered} \tag{2}$$

$$\begin{gathered}\mathrm{Cr} = 1.073 \times \mathrm{Al} + 0.094 \times \mathrm{Ex.Mn} + 0.620 \\ r = 0.99;\end{gathered} \tag{3}$$

$$\begin{gathered}\mathrm{Co} = 0.471 \times \mathrm{Al} + 0.137 \times \mathrm{MnO_2} + 0.442 \\ r = 0.95;\end{gathered} \tag{4}$$

$$\begin{gathered}\mathrm{Cu} = 0.448 \times SA + 0.208 \times TOC + 0.233 \times \mathrm{Mn} + 0.860 \\ r = 0.95;\end{gathered} \tag{5}$$

$$\begin{gathered}\mathrm{Pb} = 0.747 \times \mathrm{Al} + 0.129 \times \mathrm{MnO_2} + 0.594 \\ r = 0.95;\end{gathered} \tag{6}$$

$$\mathrm{Hg} = -0.357 \times Mz + 0.269 \times TOC + 0.270 \times SA - 0.270 \times \mathrm{Al} - 0.904 \qquad r = 0.89; \tag{7}$$

$$\mathrm{Ni} = 0.421 \times \mathrm{Ex.Fe} - 0.275 \times Mz + 0.167 \times \mathrm{Mn} + 0.261 \qquad r = 0.94; \tag{8}$$

$$\mathrm{Se} = 0.422 \times TOC + 0.207 \times \mathrm{MnO_2} - 0.841 \qquad r = 0.82;\ \text{and} \tag{9}$$

$$\mathrm{Zn} = 1.051 \times \mathrm{Al} + 0.092 \times \mathrm{MnO_2} + 0.895 \qquad r = 0.98, \tag{10}$$

where,

Ex.Mn is extractable manganese, mg/kg;
Mz is mean grain size, µm;
MnO_2 is manganese oxide, mg/kg;
TOC is total organic carbon, weight percent;
SA is surface area, m^2/g; and
Ex.Fe is extractable iron, mg/kg.

Assuming that most of the trace-element variation in bottom-material chemistry can be explained by the physical and chemical properties of the bottom material, it should be possible to combine these properties to estimate trace-element concentrations in bottom material. Furthermore, assuming that the majority of the bottom-material samples were collected from relatively uncontaminated sites, the equations could prove to be a useful tool in identifying sites with elevated trace-element concentrations.

OCCURRENCE OF TRACE ELEMENTS IN BOTTOM MATERIAL

Elevated concentrations of trace elements in bottom material may originate from point and nonpoint sources. These sources may directly contribute contaminated sediment to a stream or may contribute trace elements in the aqueous phase, which are then available to be adsorbed onto bottom material.

Identifying individual sources of trace-element contamination is difficult for two reasons. Urban or industrial areas often have multiple sources of trace-element contamination. Additionally, contaminated bottom material could remain long after the source of the contamination is gone. For these reasons, individual sources could not be easily identified on the basis of the sampling scheme for this study.

Point sources of trace elements usually are identifiable, such as the end of a pipe that has a fixed location. Point sources include industrial and municipal wastewater discharges. Nonpoint sources of contamination usually are characterized by runoff from an area rather than a pipe and are associated mainly with land use. Nonpoint sources may include urban-atmospheric deposition, agricultural runoff, unintentional spills, and additions of herbicides or biocides into water bodies.

Industrial sources of trace elements may include automotive industries, nuclear-energy production, paper mills, tanneries, petroleum industries and refineries, electrical component manufacturing, wood preserving, metal plating, metal manufacturing, and pilings and wharves. Some trace elements are associated with a specific industry. Mercury, selenium, and arsenic commonly are associated with pesticides, chemical plants, and agricultural runoff, whereas zinc commonly is associated with pulp and paper mills.

Trace-element concentrations measured in bottom-material samples, as well as the concentrations estimated using equations 1 to 10 are listed in table 1. Replicate analyses of trace-element concentrations detected near the lowest analytical limit may vary as much as 100 percent (A.J. Horowitz, oral commun., 1995). The variations are a result of analytical errors associated with determining the concentrations, such as variations in extraction efficiencies. Unless near the reporting limit, concentrations plus or minus 10 percent are considered to be statistically valid. Concentrations exceeding the estimate by more than about 20 percent are indicative of contaminated areas and, in table 1, are shaded in those instances for which the differences are considered to be statistically valid. In situ water-quality data, measured trace-element concentrations, physical properties, and chemical properties of the bottom material are arranged by basin and are listed in appendix A, tables A1 to A6.

Pearl River (Pearl River Basin)

Sites 1 to 3 on the Pearl River were located in the northern and central areas of the basin. The other six sites were located on the southern reaches of the river and distributed evenly between the eastern, middle, and western branches of the Pearl River (fig. 3).

The highest concentrations of all trace elements in bottom-material samples collected from the Pearl River were detected in samples from site 7 (table 1). Samples from site 8 also had high concentrations of all of the trace elements except mercury and selenium, compared to samples from the other Pearl River sites.

Sites 7 and 8 tended to exhibit higher trace-element concentrations in bottom material than were estimated for most of the trace elements analyzed, with the exception of copper, lead, and selenium. However, only sites 7 and 8 were identified by the nickel trace-element equation as sites that may be adversely affected by human activities. Concentrations of nickel at sites 7 and 8 (17 and 12 mg/kg) exceeded the estimated background nickel concentrations (12 and 7 mg/kg) by 29 and 42 percent. The nickel equation utilizes Ex.Fe, mean grain size, and manganese as independent variables; therefore, nickel is strongly correlated with these sediment characteristics. Although the measured manganese concentration at site 7 did not differ substantially from manganese concentrations at the remaining sites, mean grain size was lower and the Ex.Fe concentration was substantially higher than at the other sites (app. A, table A1). Site 8 also had a substantially higher Ex.Fe concentration than the other sites.

Sites 7 and 8 were located on the Old Pearl River and the Middle River, south of U.S. Highway 90. As the surrounding area is sparsely populated and has little or no industry, the primary sources of nickel and other trace elements are unknown.

Tickfaw River (Lake Pontchartrain-Lake Maurepas Basin)

All nine sampling sites in the Lake Pontchartrain-Lake Maurepas Basin were located on the Tickfaw River with the exception of site 7, which was on the Blood River about 3 mi north of its confluence with the Tickfaw River (fig. 4). The Blood River is a major contributor of sediment and water to the Tickfaw River. For this reason, site 7 was selected to identify any appreciable differences between the two rivers.

Table 1.--Comparison of measured and estimated background trace-element concentrations in bottom material from selected streams in coastal Louisiana, 1991-92

[Meas, measured concentrations, in milligrams per kilogram; estm, estimated concentrations, in milligrams per kilogram; <, less than. Highlighted areas identify concentrations generally greater than 20 percent higher than the estimated concentrations for the sediment in which they were sampled]

	Antimony		Arsenic		Chromium		Cobalt		Copper		Lead		Mercury		Nickel		Selenium		Zinc	
Site no.	Meas	Estm	Meas	Estm	Meas	Estm	Meas	Estm	Meas	Estm	Meas	Estm	Meas	Estm	Meas	Estm	Meas	Estm	Meas	Estm
Pearl River (Pearl River Basin)																				
1	<0.1	0.1	0.4	0.2	1	1	3	2	<1	<1	1	2	<0.01	<0.01	3	2	<0.1	<0.1	2	2
2	.1	.1	.4	.3	1	1	2	2	<1	<1	2	2	.02	<.01	3	2	.1	<.1	3	2
3	.2	.2	.7	.6	3	3	3	4	2	1	3	4	<.01	.01	3	4	<.1	.2	5	5
4	<.1	.1	.6	.4	1	1	3	2	<1	<1	1	2	<.01	<.01	6	3	<.1	<.1	3	2
5	.1	.2	1.0	1.1	7	7	4	4	2	3	3	5	.02	.02	6	5	<.1	.1	11	10
6	.1	.2	.9	1.0	6	5	4	<1	2	3	3	<1	.01	.02	5	5	.1		9	<1
7	.5	.4	4.8	4.0	39	34	11	8	9	12	13	17	.04	.04	17	12	.3	.4	51	50
8	.3	.3	3.1	2.4	21	19	8	6	5	7	7	11	.02	.03	12	7	.1	.2	30	28
9	.1	.1	.8	.6	3	2	3	3	1	1	4	3	.01	.01	2	3	<.1	.1	4	3
Tickfaw River (Lake Pontchartrain-Lake Maurepas Basin)																				
1	0.1	0.1	0.7	1.1	3	3	3	4	3	3	5	4	0.02	0.01	3	4	0.2	0.1	6	5
2	.1	.1	.4	.4	1	1	2	2	1	1	4	2	.01	.01	1	2	.1	.1	1	2
3	.1	.2	.4	.7	2	2	2	2	1	1	3	3	.01	.01	3	3	.1	.1	3	4
4	.1	.1	.3	.4	1	1	2	2	1	1	3	2	.01	.01	2	3	.1	.1	2	2
5	.3	.4	1.4	2.2	18	19	4	6	5	6	10	11	.04	.02	8	7	.3	.2	25	26
6	.5	.6	4.4	4.9	42	46	9	10	11	16	22	22	.08	.05	16	15	.5	.4	60	66
7	.6	.7	3.8	4.7	39	42	8	10	11	12	22	21	.05	.06	15	17	.4	.4	62	60
8	.8	.8	6.9	6.8	57	60	11	12	16	20	29	28	.09	.08	23	24	.6	.5	90	87
9	.7	.8	6.7	6.6	44	50	10	12	14	19	23	26	.09	.08	19	26	.6	.6	71	74
Bayou Lafourche (Mississippi River Delta Basin)																				
1	0.7	0.8	7.5	6.4	46	49	12	11	18	14	28	25	0.06	0.05	26	24	0.4	0.4	92	71
2	1.0	.9	12	9.2	68	67	15	14	29	22	33	32	.08	.08	38	33	.6	.5	134	99
3	1.0	.8	13	9.6	71	71	15	14	31	24	38	33	.11	.08	38	32	.9	.5	139	105
4	.8	.8	16	9.6	70	64	13	13	31	24	50	31	.09	.08	35	34	.9	.5	153	94
5	.9	.7	10	7.5	59	57	13	12	53	13	57	28	.20	.06	29	29	.5	.4	208	86
6	.7	.7	9.0	7.2	57	54	13	12	36	15	31	27	.09	.07	29	30	.6	.6	163	82
7	.4	.3	2.2	2.6	18	29	7	8	4	3	12	15	.01	.01	14	9	.1	.1	41	43
8	.4	.4	5.6	4.7	32	39	9	10	10	9	17	21	.03	.03	19	15	.3	.3	68	58
9	.5	.5	5.1	4.9	38	44	9	10	12	9	17	23	.03	.03	20	16	.3	.3	66	66

Table 1.--Comparison of measured and estimated background trace-element concentrations in bottom material from selected streams in coastal Louisiana, 1991-92--Continued

	Antimony		**Arsenic**		**Chromium**		**Cobalt**		**Copper**		**Lead**		**Mercury**		**Nickel**		**Selenium**		**Zinc**	
Site no.	**Meas**	**Estm**	**Meas**	**Estm**	**Meas**	**Estm**	**Meas**	**Estm**	**Meas**	**Estm**	**Meas**	**Estm**	**Meas**	**Estm**	**Meas**	**Estm**	**Meas**	**Estm**	**Meas**	**Estm**
Vermilion River (Atchafalaya-Teche-Vermilion Basin)																				
1	0.5	0.7	7.6	7.2	49	54	10	11	20	16	25	26	0.04	0.06	25	23	0.4	0.4	91	79
2	.6	.8	8.0	7.0	51	53	10	11	25	15	36	25	.08	.07	26	24	.4	.4	141	76
3	.6	.7	6.6	5.9	45	47	7	10	21	12	28	22	.07	.06	20	22	.3	.3	107	66
4	.5	.9	7.2	6.8	49	52	9	11	23	16	25	25	.06	.10	23	30	.4	.4	117	75
5	.5	.8	6.7	7.0	48	51	9	11	21	16	30	25	.07	.07	21	24	.4.	.4	109	74
6	.5	.7	6.8	6.5	43	47	9	11	21	14	29	23	.07	.06	20	18	.3	.4	119	68
7	.7	.7	8.4	6.8	32	40	11	11	14	16	19	23	.06	.06	18	23	.3	.5	92	61
8	.6	.7	5.8	5.7	35	41	7	10	14	12	18	22	.05	.06	16	22	.3	.4	80	62
9	.6	.9	10	10	64	71	13	15	25	25	33	35	.08	.07	31	31	.6	.7	114	105
Calcasieu River (Calcasieu-Mermentau River Basin)																				
1	0.3	0.4	2.2	2.3	20	22	6	6	7	6	24	12	0.07	0.04	6	9	0.4	0.2	26	31
2	.6	.6	5.8	6.0	63	50	12	10	26	13	40	23	.19	.06	16	19	.7	.3	81	72
3	.3	.3	1.7	1.8	15	16	5	5	8	4	19	10	.11	.03	6	8	.2	.2	27	24
4	.5	.6	5.2	6.3	61	52	12	12	34	15	45	27	.47	.06	20	20	.5	.4	80	81
5	.5	.6	5.5	5.7	45	44	11	10	18	13	67	22	.13	.05	15	18	.4	.3	68	66
6	.4	.5	5.2	4.9	44	44	12	10	14	13	22	22	.15	.06	16	17	.5	.4	62	66
7	.4	.5	4.6	4.6	42	43	9	10	15	11	24	22	.15	.06	18	16	.4	.3	61	65
8	.4	.6	5.6	6.0	44	48	12	10	15	13	22	23	.11	.05	16	15	.3	.3	63	70
9	.5	.5	9.4	8.0	50	53	12	11	14	16	22	25	.07	.04	30	16	.2	.3	84	78
10	.5	.6	7.3	9.3	62	60	13	12	17	16	26	29	.04	.05	36	17	.3	.2	87	93
Sabine River (Sabin River Basin)																				
1	0.4	0.5	3.4	4.1	26	27	12	9	6	13	20	17	0.05	0.04	8	12	0.2	0.4	38	42
2	.4	.5	2.8	2.8	26	27	8	7	22	11	58	13	.02	.04	7	8	.4	.4	64	34
3	.5	.6	12	7.3	52	44	11	10	18	17	23	23	.04	.07	22	21	.4	.3	65	69
4	.2	.4	2.1	1.8	13	15	5	5	4	3	<1	9	.03	.02	<1	7	<.1	.1	22	21
5	.4	.4	4.2	4.2	30	26	10	8	8	8	17	16	.03	.04	11	15	.3	.2	56	42
6	.3	.5	5.4	4.6	31	34	10	9	8	6	18	18	.02	.02	13	15	.1	.2	55	50
7	.4	.5	6.0	5.0	32	36	11	9	8	11	18	19	.02	.04	8	17	.1	.2	59	54
8	.5	.8	10	9.2	68	64	14	14	17	23	32	33	.04	.06	29	26	.3	.5	91	95
9	.5	.7	8.6	7.4	45	50	13	12	13	21	25	27	.03	.06	24	23	.3	.5	66	75

Measured trace-element concentrations in bottom material did not significantly exceed the estimated background concentrations at any of the nine sites sampled along the Tickfaw River and Blood River (table 1). The low trace-element concentrations are indicative of the lack of industry, urbanization, and related trace-element inputs within the basin.

Bayou Lafourche (Mississippi River Delta Basin)

Bottom material at nine sites on Bayou Lafourche was sampled for trace elements and chemical properties, and field water-quality measurements also were made at each of the sites (app. A, table A3). Sites 1 to 5 were located in a reach of the bayou that is more densely populated than the downstream reach; site 1 was in downtown Donaldsonville, sites 2 and 3 were between Donaldsonville and Thibodaux, site 4 was within the city limits of Thibodaux, and site 5 was on the south end of Golden Meadow (fig. 5). Site 6 was 1 mi south of the gated hurricane protection levee system below Golden Meadow. The remaining three sites were on or in the gulf outlet area on Belle Pass, Pass Fourchon, and the main stem of Bayou Lafourche just north of Belle Pass and Pass Fourchon.

There are many sources of trace elements in and around Bayou Lafourche because of the numerous towns, industries, highways, and bridges in the Mississippi River Delta Basin and the extensive use of the bayou as an avenue for boat traffic. Most of the bayou is bound by La. Highway 1 to the west and La. Highway 308 to the east (fig. 5), and there are numerous bridge crossings along the bayou's reach. The banks of Bayou Lafourche, especially along La. Highways 1 and 308, are very urbanized and support many marine, petrochemical, and fishing industries associated with the bayou. In addition, farmlands are present behind the towns along Highways 1 and 308.

The physical and chemical characteristics of the bottom material are substantially different at sites 7 to 9 than at the other sites (app. A, table A3). The mean grain size is much greater, ranging from 76 to 119 μm, as compared to 15 to 24 μm at sites 1 to 6. This is counter to the usual pattern in coastal Louisiana streams, where mean grain size decreases toward the mouth. This may be caused in part by dredging and channel maintenance activities in the channels and passes near the mouth. The concentrations of iron and manganese oxide coatings also are much lower at sites 7 to 9. The combination of reduced surface area and lower concentrations of oxide coatings results in fewer available sites for trace-element adsorption.

Trace-element concentrations in bottom material tended to increase in sites 1 to 6, and decrease in sites 7 to 9 (table 1). These data may indicate that urbanized areas (sites 1 to 6) in Bayou Lafourche are a more likely source of trace elements than the industrialized area (sites 7 to 9); however, the comparatively low concentrations of trace elements at sites 7 to 9 also may have been due to the effects of salinity. Based upon the specific-conductance data collected at the sampling sites (app. A, table A3), the freshwater-saltwater interface appears to be located between sites 5 and 6. Trace elements tend to precipitate out of suspension at the interface, which could explain the lower trace-element concentrations downstream from the interface, at sites 7 to 9 (Forstner and Wittmann, 1981, p. 191-194).

Elevated concentrations of arsenic and copper were detected in bottom material at sites 2 to 6 in Bayou Lafourche (table 1). Arsenic is strongly associated with chemical production and agricultural runoff. Copper is used extensively by the electrical, metal-working, paper-producing, tannery, and refinery industries. Sites 2 to 6 represent various land uses and cover a large part of the Bayou Lafourche study area. Given the many possible sources of arsenic and copper between sites 2 and 6 and the extent of the area affected, a single point or nonpoint source is unlikely.

Concentrations of lead in bottom material at sites 4 and 5 (50 and 57 mg/kg) exceeded estimated background concentrations (31 and 28 mg/kg) for these sites (table 1). Site 4 was at Thibodaux and site 5 was at the town of Golden Meadow. Municipal operations, surface runoff, burning of leaded fossil fuels, and several industrial activities are possible sources of lead. Although use of leaded fuel has declined, its past use and subsequent association with bottom material is still evident.

The mercury concentration in bottom material at site 5 (0.20 mg/kg) significantly exceeded the estimated background concentration (0.06 mg/kg) for this site (table 1). The site was located on the south end of Golden Meadow, which is heavily used by the fishing and marine industries. Although mercury is commonly associated with the chemical industry and agricultural runoff, mercury also can be associated with marine antifouling paints, ocean dumping, and dredging (Lyman and others, 1986).

Zinc concentrations in bottom material at sites 1 to 6 were identified as affected by anthropogenic sources. Zinc is a common trace element in corrosion-resistant paints and is also associated with pulp- and paper-producing industries. Bottom material at sites 2 to 6 has been affected by several trace elements. Given the fact that most of the urbanization along the bayou is between sites 1 and 6, urbanization is a likely source of trace elements to the bayou in these areas.

Bottom material at sites 2 to 6 appears to be more adversely affected than at the other sampling sites in the Mississippi River Delta Basin. Four trace elements (lead, mercury, nickel, and zinc) exceeded the ER-L in the reach of Bayou Lafourche between sites 2 and 5, as listed in the table below:

Site	Lead	Mercury	Nickel	Zinc
	ER-L (mg/kg)			
	35	0.15	30	170
	Measured concentration (mg/kg) [dash indicates concentration less than the ER-L]			
2	—	—	38	—
3	38	—	38	—
4	50	—	35	—
5	57	0.20	—	208

This supports the results from the estimation equations indicating that Bayou Lafourche is adversely affected by trace elements in areas upstream from the saltwater-freshwater interface. Agricultural runoff and urbanization, especially in the upper parts of the basin, and marine and fishing industries in the lower parts of the basin, are probably the primary contributors of trace elements to Bayou Lafourche.

Vermilion River (Atchafalaya-Teche-Vermilion Basin)

Bottom material at nine sites was sampled for trace elements and chemical properties and field water-quality measurements also were made at each site along the Vermilion River (app. A, table A4), from the La. Highway 729 bridge (site 1, fig. 6) south to Vermilion Bay. The northern and central reaches of the river were represented by sites 1 to 5, and the southern reaches by sites 6 to 9. The northern and central parts of the basin are the most urbanized areas; however, the southern part of the basin also has smaller areas of urbanization (fig. 6).

The concentration of arsenic in bottom material at site 7 in the Vermilion River (8.4 mg/kg) was identified as being above the background concentration (6.8 mg/kg) for this site (table 1). Site 7 was about 0.5 mi south of the Intracoastal Waterway. Arsenic is associated mainly with chemical production and agricultural runoff.

Sites 2 to 6 along the Vermilion River had elevated concentrations of copper in bottom material. These sites were primarily in and around urbanized areas. Industry, municipal operations, croplands, storm sewers, petroleum storage and transport, and surface-water runoff are suspected sources of copper contamination (Louisiana Department of Environmental Quality, 1990). These are also potential sources of several other trace elements.

Lead and zinc concentrations in bottom material at site 2 (36 and 141 mg/kg) also were above estimated background levels (25 and 76 mg/kg) for this site (table 1). The lead concentration (36 mg/kg) exceeded the ER-L threshold concentration (35 mg/kg), as well. Site 2 was located on the south end of Lafayette. Considering the extent of urbanization around and north of site 2, the City of Lafayette and its associated industry, croplands, petroleum activities, and surface runoff are likely sources of lead and zinc to the river.

Measured concentrations of zinc in bottom material at sites 2 to 8 exceeded the background concentrations defined by the zinc estimation equation. Sites 1 to 6 represent the most urbanized areas of the Vermilion River. Sites 7 to 9 were south of the Intracoastal Waterway in an area mainly used by the fishing and petrochemical industries.

The measured trace-element concentrations at site 9 were not considered to be significantly elevated above estimated background concentrations; however, concentrations of six trace elements at site 9 were as high as or higher than concentrations at the other Vermilion River sites. This finding is not unexpected, because the Ex.Fe and Ex.Mn coatings and the surface area at site 9 are substantially greater than at other sites. Nickel at site 9 (31 mg/kg) exceeded the ER-L threshold concentration (30 mg/kg). The DEQ (1990) cites the suspected sources of elevated trace-element concentrations in this southern area of the Vermilion River as industry, agriculture, petroleum activities, and dam construction.

Calcasieu River (Calcasieu-Mermentau River Basin)

Samples of bottom material were collected from 10 sites along the Calcasieu River (fig. 7) and analyzed for trace elements and for physical and chemical properties (app. A, table A5). Field water-quality measurements also were taken at the sites, which were located from 2 mi upstream from I-10, north of the city of Lake Charles, to the Calcasieu River outlet into the Gulf of Mexico. Half of the sites (sites 1 to 5) were north of the Intracoastal Waterway, which crosses the Calcasieu River just above the north end of Calcasieu Lake (fig. 7). Site 6 was at Devil's Elbow on the Intracoastal Waterway. The remaining four sites were in the central and southern reaches of the river.

Demas and Demcheck (1988) reported on the fate and transport of synthetic organic compounds and trace elements in the lower Calcasieu River. During that study, barium, chromium, copper, mercury, iron, and manganese were measured in detectable concentrations in water and bottom material. Previously, during the early 1970's, concentrations of chromium and mercury had been detected in the water, bottom material, and biota. Results from the 1988 study indicated that the area between sites 3 and 4 has been heavily affected by human activities.

Sites 2 to 4 on the Calcasieu River were between the south end of the city of Lake Charles and about 3 mi below Prien Lake. Bottom material sampled at these sites had copper concentrations above estimated background concentrations (table 1). In addition, lead concentrations at sites 2 to 5 (1 mi north of the Intracoastal Waterway) exceeded the estimated background concentrations. Industry, urban runoff, and unknown nonpoint sources are listed by DEQ (1990) as possible sources of elevated trace-element concentrations in this area. This area of the basin is used mainly for industry, fishing, agriculture, and navigation, all of which are potential sources of trace elements.

Mercury concentrations in bottom material at sites 2 to 8, identified as being above estimated concentrations, were the highest mercury concentrations determined during the study, with the exception of concentrations at two sites in Bayou Lafourche (table 1). Mercury commonly is associated with fertilizers, paints, batteries, and biocides. Sites 2 to 8 are distributed over a large area of the Calcasieu River, suggesting that the elevated concentrations are the result of a widespread or long-term input.

Nickel concentrations at sites 9 and 10 (30 and 36 mg/kg) significantly exceeded estimated concentrations (16 and 17 mg/kg) for these sites (table 1). Site 9 was near the south end of Calcasieu Lake, and site 10 was at the Calcasieu River's confluence with the Gulf of Mexico. Industrial, municipal, and urban runoff are identified by DEQ (1990) as potential sources of pollution in these areas. The primary land uses in these areas are industry, fishing, and navigation. Three trace elements (lead, mercury, and nickel) equaled or exceeded the ER-L threshold concentrations at sites 2, 4 to 7, 9, and 10, as listed in the table below, and, therefore, may pose a threat to biota at these six sites.

	Lead	Mercury	Nickel
	ER-L (mg/kg)		
	35	0.15	30
Site	Measured concentration (mg/kg) [dash indicates concentration less than the ER-L]		
2	40	0.19	—
4	45	.47	—
5	67	—	—
6	—	.15	—
7	—	.15	—
9	—	—	30
10	—	—	36

Sabine River (Sabine River Basin)

Nine bottom-material samples were collected from the Sabine River Basin (fig. 8). These samples were analyzed for trace elements, chemical properties, and field water-quality measurements (app. A, table A6). Site 1 was on Old River, a branch of the Sabine River, upstream from industrial areas near Orange, Tex. Sites 2 and 3 were within the industrial area surrounding Orange, sites 4 to 6 were in Sabine Lake, and sites 7 to 9 were concentrated in the southern part of the Sabine River.

The concentration of arsenic in bottom material at site 3 (12 mg/kg) was significantly elevated above the estimated background concentration (7.3 mg/kg) (table 1). Arsenic is commonly present in many petroleum products used by nearby industries.

Bottom-material samples from site 2 also had concentrations of copper, lead, and zinc (22, 58, and 64 mg/kg) that significantly exceeded estimated concentrations (11, 13, and 34 mg/kg) (table 1). Lead at site 2 (58 mg/kg) exceeded the ER-L threshold concentration (35 mg/kg). Site 2 on the Sabine River was about 2.5 mi south of I-10 and 0.25 mi east of Orange. The town of Orange, on the west bank of the Sabine River, supports marine, fishing, and petrochemical industries. These industries are all potential sources of trace elements to the Sabine River. The Sabine River also is used extensively for navigation.

The zinc concentration in bottom material at site 5 (56 mg/kg) was significantly higher than the estimated background concentration of 42 mg/kg (table 1). Site 5 was in Sabine Lake, about 5 mi from the north end and 4.5 mi east of Port Arthur, Tex. Port Arthur is the largest port on the Sabine River. Zinc is commonly present in corrosion-resistant paints that are widely used in the marine industry.

Interbasin Comparisons

Interbasin comparisons of trace-element concentrations should be made only with careful consideration of the differences of the physical and chemical properties of the basins being compared. Although the Louisiana coastal zone has a higher percent organic matter and finer-grained sediments than other areas of the State, the substrate from Texas to Mississippi is not homogeneous. One of the major objectives of this study was to document the physical and chemical properties that make each basin unique with respect to background trace-element concentrations. These unique characteristics make comparisons difficult and possibly misleading. In the past, scientists and managers have made conclusions on whether streams have high or low concentrations of trace elements in bottom material by simply comparing concentrations among streams. This approach leads to misleading conclusions: for example, although nickel concentrations in bottom material ranged from 14 to 38 mg/kg in Bayou Lafourche, and 1 to 23 mg/kg in the Tickfaw River (table 1), neither stream is considered to have elevated concentrations of nickel using the estimation method used in this study; however, the Pearl River, with nickel concentrations ranging from 2 to 17 mg/kg, is considered to have elevated concentrations of nickel at two sites.

A few general statements can be made on trace-element concentrations in bottom-material samples from the six streams studied. Measured concentrations exceeded estimated concentrations for five trace elements on the Calcasieu River and Bayou Lafourche, four on the Vermilion River and Sabine River, one on the Pearl River, and none on the Tickfaw River (table 1). These stream groupings take into account differences in grain size, percent organic matter, and types and amounts of oxide coatings (app. A, tables A1 to A6) among the basins. Therefore, the groupings may represent a ranking of the relative amount of contamination among basins. These groupings also correspond to clusters of industrial and commercial activity, as the Calcasieu River and Bayou Lafourche have extensive petrochemical and shipping facilities, whereas the area surrounding Tickfaw River is almost exclusively agricultural and residential. Thus, the statistical analysis used in this study corroborates more traditional means of determining potential areas of anthropogenic degradation, such as land-use delineation.

SUMMARY AND CONCLUSIONS

Six streams (Pearl River, Tickfaw River, Bayou Lafourche, Vermilion River, Calcasieu River, and Sabine River) in coastal Louisiana were sampled for trace-element concentrations in bottom material during 1991-92. Nine samples of bottom material were collected from each stream except the Calcasieu River, from which 10 samples were collected. The samples were analyzed for 10 trace elements: antimony, arsenic, chromium, cobalt, copper, lead, mercury, nickel, selenium, and zinc. The minimum and maximum concentrations, in milligrams per kilogram, of each trace element and the stream in which they were detected are as follows: antimony, less than 0.1 (Pearl River) and 1 (Bayou Lafourche); arsenic, 0.3 (Tickfaw River) and 16 (Bayou Lafourche); chromium, 1 (Pearl River and Tickfaw River) and 71 (Bayou Lafourche); cobalt, 2 (Pearl River and Tickfaw River) and 15 (Bayou Lafourche); copper, less than 1 (Pearl River) and 53 (Bayou Lafourche); lead, less than 1 (Sabine River) and 67 (Calcasieu River); mercury, less than 0.01 (Pearl River) and 0.47 (Calcasieu River); nickel, less than 1 (Sabine River) and 38 (Bayou Lafourche); selenium, less than 0.1 (Pearl River and Sabine River) and 0.9 (Bayou Lafourche); and zinc, 1 (Tickfaw River) and 208 (Bayou Lafourche).

No standards for trace-element concentrations in bottom material have been established; however, effects range-low (ER-L) and effects range-median (ER-M) values represent 10th and 50th percentile concentrations that, when exceeded, may produce adverse reactions in biota. Concentrations below the ER-L indicate a minimal adverse effects range. Concentrations between the ER-L and ER-M indicate a possible adverse effects range, and concentrations above the ER-M indicate a frequent adverse effects range.

ER-L and ER-M concentrations, in milligrams per kilogram, for 8 of the 10 trace elements determined in bottom material for this study are as follows: antimony, 2 and 25; arsenic, 33 and 85; chromium, 80 and 145; copper, 70 and 390; lead, 35 and 110; mercury, 0.15 and 1.3; nickel, 30 and 50; and zinc, 170 and 270. The trace-element concentrations in bottom material from the streams were compared to the ER-L and ER-M threshold concentrations. No samples exceeded the ER-M for the eight trace elements for which ER-M values are available; however, in samples from Bayou Lafourche, concentrations of lead (38 to 57 mg/kg), mercury (0.20 mg/kg), nickel (35 to 38 mg/kg), and zinc (208 mg/kg) exceeded the ER-L threshold concentrations. In samples from the Vermilion River, concentrations of lead (36 mg/kg) and nickel (31 mg/kg) exceeded the ER-L threshold concentrations. In samples from the Calcasieu River, concentrations of lead (40 to 67 mg/kg), mercury (0.15 to 0.47 mg/kg), and nickel (30 to 36 mg/kg) exceeded the ER-L threshold concentrations. Only lead (58 mg/kg) exceeded the ER-L threshold concentration in samples from the Sabine River. Samples from the Pearl River and Tickfaw River had no concentrations that exceeded the ER-L values.

All bottom material samples were analyzed for physical and chemical properties that affect trace-element concentrations: grain size, surface area, organic matter, and iron and manganese oxide coatings. Mean grain size typically decreased and organic matter increased in a downstream direction. Each site, however, had a unique set of physical and chemical factors affecting the distribution of trace elements.

Multiple linear regression equations were used to estimate background or naturally occurring concentrations for 10 trace elements based on the physical and chemical properties of the bottom-material samples. These estimated background concentrations were compared to measured concentrations from sampling sites. This technique is valid in those instances where the measured concentrations are sufficiently above the lowest level of detection that the analytical technique used produces a high degree of confidence in the reproducibility of the results. Where such conditions existed in this study, measured trace-element concentrations exceeding the estimated background concentration by 20 percent or more were identified as being significantly elevated.

Trace-element concentrations varied in samples from the six streams. Measured concentrations in bottom material exceeded estimates for five trace elements (copper, lead, mercury, nickel, and selenium) on the Calcasieu River. Of these five trace elements, elevated mercury concentrations were the most notable, with concentrations ranging from 0.11 to 0.47 mg/kg at seven sites, compared to estimated background concentrations of 0.03 to 0.06 mg/kg. Similarly, measured concentrations exceeded estimates for five trace elements (arsenic, copper, lead, mercury, and zinc) on Bayou Lafourche. The elevated concentrations in Bayou Lafourche all were located upstream from the saltwater-freshwater interface. Increases in the ionic strength of the water column at the interface apparently has caused organic matter and associated trace elements to precipitate, resulting in low trace-element concentrations in the bottom material downstream from the interface. Measured concentrations exceeded estimates for four trace elements (arsenic, copper, lead, and zinc) on the Vermilion River and Sabine River; one (nickel) on the Pearl River, and none on the Tickfaw River. These stream groupings take into account differences in grain size, percent organic matter, and types and amounts of oxide coatings among the streams. Therefore, the groupings may represent a ranking of the relative amount of contamination among the streams. These groupings also correspond to clusters of industrial and commercial activity, as the Bayou Lafourche and Calcasieu River have extensive petrochemical and shipping facilities, whereas the area surrounding the Tickfaw River is almost exclusively agricultural and residential.

Determining the estimated background trace-element concentrations for these six streams will assist in identifying areas of trace-element contamination. This information will provide a base from which to monitor the trace-element concentrations in bottom material in the future.

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APPENDIX A

Measured trace-element concentrations and physical and chemical properties for bottom material and selected water analyses for six streams in coastal Louisiana, 1991-92

Table A1. Measured trace-element concentrations and physical and chemical properties for bottom material and selected water analyses for Pearl River (Pearl River Basin), June 20-21, 1991

[Hwy., Highway; <, less than; µm, micrometers; m^2/g, square meters per gram]

	Milligrams per kilogram										Weight percent			
Site number and description	Antimony	Arsenic	Chromium	Cobalt	Copper	Lead	Mercury	Nickel	Selenium	Zinc	Aluminum	Iron	Manganese	Titanium
1 Pearl River, 5 miles north of La. Hwy. 26 bridge	<0.1	0.4	1	3	<1	1	<0.01	3	<0.1	2	0.2	0.04	0.0006	0.02
2 Pearl River, 1/8 mile north of La. Hwy. 26 bridge	.1	.4	1	2	<1	2	.02	3	.1	3	.2	.07	.0005	.02
3 Pearl River, 2 miles south of the confluence with Bogue Chitto	.2	.7	3	3	2	3	<.01	3	<.1	5	.4	.16	.022	.07
4 West Pearl River, 1/2 mile north of Interstate Hwy. 10	<.1	.6	1	3	<1	1	<.01	6	<.1	3	.2	.10	.013	.02
5 Pearl River, 2.5 miles south of Interstate Hwy. 10 bridge	.1	1.0	7	4	2	3	.02	6	<.1	11	1.1	.39	.007	.09
6 Pearl River, 1/2 mile south of U.S. Hwy. 90 bridge	.1	.9	6	4	2	3	.01	5	.1	9	.9	.33	.004	.08
7 Old Pearl River 1/8 mile south of U.S. Hwy. 90 bridge	.5	4.8	39	11	9	13	.04	17	.3	51	4.8	1.85	.016	.37
8 Middle River, 3 miles south of U.S. Hwy. 90	.3	3.1	21	8	5	7	.02	12	.1	30	2.9	1.08	.0009	.22
9 West Pearl River channel 1/8 mile south of U.S. Hwy. 90	.1	.8	3	3	1	4	.01	2	<.1	4	.3	.17	.014	.02

Table A1. Measured trace-element concentrations and physical and chemical properties for bottom material and selected water analyses for Pearl River (Pearl River Basin), June 20-21, 1991—Continued

	Weight percent			Percentage of sample with grain size less than						Milligrams per kilogram				
Site number and description	Loss on ignition	Total organic carbon	Other organic material	2 µm	16 µm	63 µm	125 µm	Mean grain size (µm)	Surface area (m^2/g)	Fe.MnO_2	MnO_2	Fe.Fe_2O_3	Ex.Fe	Ex.Mn
1 Pearl River, 5 miles north of La. Hwy. 26 bridge	0.2	0.0	0.1	<1	<1	<1	<1	304	0.3	25	30	380	700	200
2 Pearl River, 1/8 mile north of La. Hwy. 26 bridge	.1	.0	.1	<1	<1	<1	<1	271	.3	20	20	80	200	32
3 Pearl River, 2 miles south of the confluence with Bogue Chitto	.5	.1	.4	<1	<1	<1	9	186	.6	70	140	380	700	200
4 West Pearl River, 1/2 mile north of Interstate Hwy. 10	.2	.0	.1	<1	<1	<1	<1	283	.5	30	100	140	390	120
5 Pearl River, 2.5 miles south of Interstate Hwy. 10 bridge	1.3	.4	.9	<1	6	10	11	278	2.5	340	5	700	2,200	70
6 Pearl River, 1/2 mile south of U.S. Hwy. 90 bridge	1.7	.7	1.1	<1	5	9	10	281	1.5	370	<5	720	2,800	40
7 Old Pearl River 1/8 mile south of U.S. Hwy. 90 bridge	7.6	3.0	4.5	<1	21	68	71	121	16.3	180	10	490	8,000	95
8 Middle River, 3 miles south of U.S. Hwy. 90	2.6	.7	1.9	<1	12	31	38	266	.4	340	5	540	4,100	61
9 West Pearl River channel 1/8 mile south of U.S. Hwy. 90	.4	.1	.3	<1	<1	<1	4	266	.5	85	55	240	620	110

Table A1. Measured trace-element concentrations and physical and chemical properties for bottom material and selected water analyses for Pearl River (Pearl River Basin), June 20-21, 1991--Continued

Site number and description		Depth, in meters	Specific conductance, in microsiemens per centimeter		pH		Temperature, in degrees Celsius		Dissolved oxygen, in milligrams per liter	
			Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface
1	Pearl River, 5 miles north of La. Hwy. 26 bridge	2.5	60	59	6.2	6.3	27.3	27.3	6.6	6.6
2	Pearl River, 1/8 mile north of La. Hwy. 26 bridge	4.6	56	56	6.1	6.2	27.3	27.3	6.6	6.6
3	Pearl River, 2 miles south of the confluence with Bogue Chitto	.7	70	70	6.4	6.4	28.6	28.6	5.9	5.9
4	West Pearl River, 1/2 mile north of Interstate Hwy. 10	.4	68	68	6.5	6.4	28.2	28.2	5.9	5.7
5	Pearl River, 2.5 miles south of Interstate Hwy. 10 bridge	9.7	69	75	6.1	6.3	26.9	28.5	4.9	5.5
6	Pearl River, 1/2 mile south of U.S. Hwy. 90 bridge	4.6	100	74	6.3	6.3	26.4	26.9	4.5	5.4
7	Old Pearl River 1/8 mile south of U.S. Hwy. 90 bridge	6.6	77	73	6.1	6.4	27.2	28.1	4.7	6.4
8	Middle River, 3 miles south of U.S. Hwy. 90	6.0	73	72	6.3	6.4	27.1	27.5	5.0	5.2
9	West Pearl River channel 1/8 mile south of U.S. Hwy. 90	2.8	66	66	6.2	6.3	27.9	27.9	5.8	5.7

Table A2. Measured trace-element concentrations and physical and chemical properties for bottom material and selected water analyses for Tickfaw River (Lake Pontchartrain-Lake Maurepas Basin), May 17-29, 1991

[Hwy., Highway; µm, micrometers; m^2/g, square meters per gram]

Site number and description		Milligrams per kilogram										Weight percent			
		Antimony	Arsenic	Chromium	Cobalt	Copper	Lead	Mercury	Nickel	Selenium	Zinc	Aluminum	Iron	Manganese	Titanium
1	Tickfaw River at La. Hwy. 38 bridge	0.1	0.7	3	3	3	5	0.02	3	0.2	6	0.5	0.3	0.03	0.03
2	Tickfaw River, 2 miles south of La. Hwy. 16 bridge	.1	.4	1	2	1	4	.01	1	.1	1	.2	.1	.01	.03
3	Tickfaw River at U.S. Hwy. 190 bridge	.1	.4	2	2	1	3	.01	3	.1	3	.4	.2	.01	.06
4	Tickfaw River, 1 mile south of La. Hwy. 42 bridge	.1	.3	1	2	1	3	.01	2	.1	2	.2	.1	.01	.03
5	Tickfaw River, 3 miles upstream from the confluence with Blood River	.3	1.4	18	4	5	10	.04	8	.3	25	2.7	.8	.02	.25
6	At confluence of Tickfaw and Blood Rivers	.5	4.4	42	9	11	22	.08	16	.5	60	5.7	2.0	.04	.41
7	Blood River, 3 miles north of the Tickfaw River	.6	3.8	39	8	11	22	.05	15	.4	62	5.2	1.8	.05	.44
8	At confluence of Tickfaw and Natalbany Rivers	.8	6.9	57	11	16	29	.09	23	.6	90	7.1	2.8	.05	.47
9	Tickfaw River, 1/4 mile north of Lake Maurepas	.7	6.7	44	10	14	23	.09	19	.6	71	5.6	2.4	.08	.36

Table A2. Measured trace-element concentrations and physical and chemical properties for bottom material and selected water analyses for Tickfaw River (Lake Pontchartrain-Lake Maurepas Basin), May 17-29, 1991—Continued

Site number and description	Weight percent			Percentage of sample with grain size less than						Milligrams per kilogram				
	Loss on ignition	Total organic carbon	Other organic material	2 µm	16 µm	63 µm	125 µm	Mean grain size (µm)	Surface area (m^2/g)	$Fe.MnO_2$	MnO_2	$Fe.Fe_2O_3$	Ex.Fe	Ex.Mn
1 Tickfaw River at La. Hwy. 38 bridge	0.5	0.1	0.4	<1	1	4	5	4.9	4.9	85	220	440	1,300	310
2 Tickfaw River, 2 miles south of La. Hwy. 16 bridge	.3	.1	.2	0	0	<1	<1	364	.4	35	40	95	240	70
3 Tickfaw River at U.S. Hwy. 190 bridge	.7	.2	.5	<1	2	5	6	290	.6	100	10	270	770	96
4 Tickfaw River, 1 mile south of La. Hwy. 42 bridge	.2	.1	.2	<1	<1	1	1	282	.9	75	40	260	740	90
5 Tickfaw River, 3 miles upstream from the confluence with Blood River	2.9	.6	2.3	2	28	47	50	150	6.3	770	35	1,400	4,600	360
6 At confluence of Tickfaw and Blood Rivers	8.0	2.2	5.9	4	47	74	77	64	20.6	1,100	35	1,900	6,800	360
7 Blood River, 3 miles north of the Tickfaw River	6.9	1.6	5.2	3	45	90	96	21	14.2	770	35	1,400	4,600	360
8 At confluence of Tickfaw and Natalbany Rivers	10.1	2.8	7.3	9	55	93	95	21	28.1	1,300	50	3,500	9,900	460
9 Tickfaw River, 1/4 mile north of Lake Maurepas	10.2	3.1	7.1	5	40	88	93	24	20.9	2,000	100	3,600	10,000	820

Table A2. Measured trace-element concentrations and physical and chemical properties for bottom material and selected water analyses for Tickfaw River (Lake Pontchartrain-Lake Maurepas Basin), May 17-29, 1991--Continued

Site number and description		Depth, in meters	Specific conductance, in microsiemens per centimeter		pH		Temperature, in degrees Celsius		Dissolved oxygen, in milligrams per liter	
			Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface
1	Tickfaw River at La. Hwy. 38 bridge	1.5	58	57	5.8	5.7	22.2	22.2	7.5	7.5
2	Tickfaw River, 2 miles south of La. Hwy. 16 bridge	.9	58	58	6.1	6.0	21.8	21.8	7.6	7.4
3	Tickfaw River at U.S. Hwy. 190 bridge	1.8	57	57	6.3	6.1	21.9	21.8	7.3	7.2
4	Tickfaw River, 1 mile south of La. Hwy. 42 bridge	2.7	60	61	6.1	5.9	23.5	23.3	6.8	6.7
5	Tickfaw River, 3 miles upstream from the confluence with Blood River	4.6	54	58	5.2	5.3	24.4	24.5	3.7	3.7
6	At confluence of Tickfaw and Blood Rivers	4.0	55	58	5.4	5.3	24.7	25.2	3.4	2.3
7	Blood River, 3 miles north of the Tickfaw River	3.0	61	64	5.4	5.5	24.7	26.1	.1	.3
8	At confluence of Tickfaw and Natalbany Rivers	5.8	55	90	5.5	5.8	25.2	26.4	1.5	.2
9	Tickfaw River, 1/4 mile north of Lake Maurepas	4.0	62	78	5.6	5.8	25.4	26.8	1.5	1.3

Table A3. Measured trace-element concentrations and physical and chemical properties for bottom material and selected water analyses for Bayou Lafourche (Mississippi River Delta Basin), April 24-26, 1991

[Hwy., Highway; µm, micrometers; m^2/g, square meters per gram]

Site number and description	Milligrams per kilogram										Weight percent			
	Antimony	Arsenic	Chromium	Cobalt	Copper	Lead	Mercury	Nickel	Selenium	Zinc	Aluminum	Iron	Manganese	Titanium
1 Bayou Lafourche, downtown Donaldsonville, La.	0.7	7.5	46	12	18	28	0.06	26	0.4	92	5.6	2.3	0.08	0.37
2 Bayou Lafourche at La. Hwy. 70 bridge	1.0	11.5	68	15	29	33	.08	38	.6	134	7.3	3.5	.10	.43
3 Bayou Lafourche at Hwy. 1011, upstream from Thibodaux, La.	1.0	13.0	71	15	31	38	.11	38	.9	139	7.8	3.8	.09	.40
4 Bayou Lafourche, about 100 feet north of weir, downtown Thibodaux, La.	.8	16.0	70	13	31	50	.09	35	.9	153	7.1	3.7	.10	.34
5 Bayou Lafourche at La. Hwy. 308, Golden Meadow, La.	.9	10.0	59	13	53	57	.20	29	.5	208	6.8	3.2	.05	.36
6 Bayou Lafourche, 1/8 mile south of La. Hwy. 308 bridge, south of Golden Meadow, La.	.7	9.0	57	13	36	31	.09	29	.6	163	6.4	2.9	.06	.34
7 Pass Fourchon bridge, left	.4	2.2	18	7	4	12	.01	14	.1	41	4.0	1.0	.02	.15
8 Bayou Lafourche above Belle Pass and Pass Fourchon	.4	5.6	32	9	10	17	.03	19	.3	68	4.9	1.8	.04	.22
9 Belle Pass, right	.5	5.1	38	9	12	17	.03	20	.3	66	5.4	1.9	.04	.26

Table A3. Measured trace-element concentrations and physical and chemical properties for bottom material and selected water analyses for Bayou Lafourche (Mississippi River Delta Basin), April 24-26, 1991—Continued

Site number and description	Weight percent			Percentage of sample with grain size less than				Mean grain size (µm)	Surface area (m^2/g)	Milligrams per kilogram				
	Loss on ignition	Total organic carbon	Other organic material	2 µm	16 µm	63 µm	125 µm			Fe.MnO_2	MnO_2	Fe.Fe_2O_3	Ex.Fe	Ex.Mn
1 Bayou Lafourche, downtown Donaldsonville, La.	13.7	1.1	12.6	6	55	97	99	24	14.6	1,000	74	3,000	8,300	660
2 Bayou Lafourche at La. Hwy. 70 bridge	8.3	1.7	6.7	3	61	98	99	15	30.6	1,600	120	5,000	12,000	910
3 Bayou Lafourche at Hwy. 1011, upstream from Thibodaux, La.	9.0	2.1	6.9	3	44	92	98	21	35.3	1,700	110	6,200	15,000	800
4 Bayou Lafourche, about 100 feet north of weir, downtown Thibodaux, La.	8.1	1.7	6.4	18	62	95	97	16	38.1	1,700	100	7,700	14,000	4,000
5 Bayou Lafourche at La. Hwy. 308, Golden Meadow, La.	6.7	1.8	5.0	10	45	89	96	20	13.3	1,600	61	5,800	15,000	410
6 Bayou Lafourche, 1/8 mile south of La. Hwy. 308 bridge, south of Golden Meadow, La.	9.8	3.2	6.6	11	53	91	97	19	13.1	1,400	69	4,600	14,000	450
7 Pass Fourchon bridge, left	2.3	.3	1.9	1	4	13	25	119	2.3	420	13	1,100	3,800	110
8 Bayou Lafourche above Belle Pass and Pass Fourchon	5.7	1.0	4.6	3	13	41	66	76	9.7	880	39	2,300	8,000	270
9 Belle Pass, right	5.4	.9	4.4	5	25	49	60	76	9.0	970	45	2,500	8,300	300

Table A3. Measured trace-element concentrations and physical and chemical properties for bottom material and selected water analyses for Bayou Lafourche (Mississippi River Delta Basin), April 24-26, 1991—Continued

Site number and description		Depth, in meters	Specific conductance, in microsiemens per centimeter		pH		Temperature, in degrees Celsius		Dissolved oxygen, in milligrams per liter	
			Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface
1	Bayou Lafourche, downtown Donaldsonville, La.	1.8	144	144	7.2	7.2	7.2	7.2	7.8	7.7
2	Bayou Lafourche at La. Hwy. 70 bridge	1.5	190	193	7.0	7.0	21.7	21.8	5.5	5.5
3	Bayou Lafourche at Hwy. 1011, upstream from Thibodaux, La.	2.4	142	177	6.6	6.8	20.4	21.1	6.7	6.4
4	Bayou Lafourche, about 100 feet north of weir, downtown Thibodaux, La.	1.5	213	213	7.0	7.0	22.0	22.0	6.0	6.0
5	Bayou Lafourche at La. Hwy. 308, Golden Meadow, La.	2.7	425	433	7.0	7.1	24.7	24.9	6.4	6.8
6	Bayou Lafourche, 1/8 mile south of La. Hwy. 308 bridge, south of Golden Meadow, La.	2.4	6,200	1,620	7.5	7.6	24.8	25.4	7.1	7.5
7	Pass Fourchon bridge, left	2.7	30,700	29,800	8.0	8.1	24.8	25.6	5.8	7.1
8	Bayou Lafourche above Belle Pass and Pass Fourchon	6.1	30,000	29,000	8.3	8.6	23.8	24.2	5.4	9.0
9	Belle Pass, right	6.1	28,300	28,300	8.7	8.7	23.7	24.0	9.4	9.4

Table A4. Measured trace-element concentrations and physical and chemical properties for bottom material and selected water analyses for Vermilion River (Atchafalaya-Teche-Vermilion Basin), December 16, 1991-January 2, 1992

[Hwy., Highway; µm, micrometers; m²/g, square meters per gram; ND, no data]

	Milligrams per kilogram										Weight percent			
Site number and description	**Antimony**	**Arsenic**	**Chromium**	**Cobalt**	**Copper**	**Lead**	**Mercury**	**Nickel**	**Selenium**	**Zinc**	**Aluminum**	**Iron**	**Manganese**	**Titanium**
1 Vermilion River above La. Hwy. 729 bridge	0.5	7.6	49	10	20	25	0.04	25	0.4	91	6.3	2.8	686	0.38
2 Vermilion River at Hwy. 3073 bridge	.6	8.0	51	10	25	36	.08	26	.4	141	6.1	2.7	704	.38
3 Vermilion River at Milton, La.	.6	6.6	45	7	21	28	.07	20	.3	107	5.6	2.3	520	.38
4 Vermilion River at La. Hwy. 14 bridge	.5	7.2	49	9	23	25	.06	23	.4	117	6.0	2.7	616	.40
5 Vermilion River at Bancker Ferry Crossing	.5	6.8	48	9	21	30	.07	21	.4	109	5.9	2.7	660	.38
6 Vermilion River, 1/2 mile north of Intracoastal Waterway	.5	6.8	43	9	21	29	.07	20	.3	119	5.6	2.5	573	.35
7 Vermilion River, 1/2 mile south of Intracoastal Waterway	.7	8.4	32	11	14	19	.06	18	.3	92	4.6	2.4	875	.30
8 Vermilion River, 2 miles south of Intracoastal Waterway, in Little Vermilion Bay	.6	5.8	35	7	14	18	.05	16	.3	80	4.9	2.1	596	.31
9 Vermilion River, 5 miles south of Intracoastal Waterway, at Vermilion Bay	.6	10.2	64	13	25	33	.08	31	.6	114	7.4	3.8	1,490	.38

Table A4. Measured trace-element concentrations and physical and chemical properties for bottom material and selected water analyses for Vermilion River (Atchafalaya-Teche-Vermilion Basin), December 16, 1991-January 2, 1992—Continued

	Weight percent			Percentage of sample with grain size less than						Milligrams per kilogram				
Site number and description	**Loss on ignition**	**Total organic carbon**	**Other organic material**	**2 µm**	**16 µm**	**63 µm**	**125 µm**	**Mean grain size (µm)**	**Surface area (m^2/g)**	**Fe.MnO_2**	**MnO_2**	**Fe.Fe_2O_3**	**Ex.Fe**	**Ex.Mn**
1 Vermilion River above La. Hwy. 729 bridge	6.8	1.6	5.3	2	42	90	97	22	19.9	970	56	3,200	0.8	560
2 Vermilion River at Hwy. 3073 bridge	6.7	2.0	4.8	2	50	94	99	18	14.2	850	52	3,600	.8	590
3 Vermilion River at Milton, La.	5.1	1.2	3.9	3	56	95	99	16	14.7	700	34	3,100	.7	420
4 Vermilion River at La. Hwy. 14 bridge	6.5	2.0	4.5	4	74	95	98	8	17.5	900	57	3,800	.8	550
5 Vermilion River at Bancker Ferry Crossing	5.6	1.7	3.9	7	53	88	97	20	17.1	900	60	3,800	.8	580
6 Vermilion River, 1/2 mile north of Intracoastal Waterway	5.9	1.8	4.1	3	36	90	98	24	15.2	900	47	3,400	.5	450
7 Vermilion River, 1/2 mile south of Intracoastal Waterway	6.0	1.8	4.2	2	32	78	96	28	15.4	720	130	2,900	.8	670
8 Vermilion River, 2 miles south of Intracoastal Waterway, in Little Vermilion Bay	5.5	1.8	3.8	5	41	89	99	22	10.7	950	71	2,400	.8	520
9 Vermilion River, 5 miles south of Intracoastal Waterway, at Vermilion Bay	10.1	3.0	7.1	1	28	92	98	25	24.8	1,200	200	5,300	1.3	1,400

Table A4. Measured trace-element concentrations and physical and chemical properties for bottom material and selected water analyses for Vermilion River (Atchafalaya-Teche-Vermilion Basin), December 16, 1991-January 2, 1992—Continued

Site number and description		Depth, in meters	Specific conductance, in microsiemens per centimeter		pH		Temperature, in degrees Celsius		Dissolved oxygen, in milligrams per liter	
			Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface
1	Vermilion River above La. Hwy. 729 bridge	2.2	90	90	6.8	6.8	14.9	14.9	5.2	5.0
2	Vermilion River at Hwy. 3073 bridge	3.0	115	116	6.8	6.8	15.2	15.2	5.7	5.9
3	Vermilion River at Milton, La.	2.9	130	130	6.6	6.7	12.6	12.5	7.1	6.7
4	Vermilion River at La. Hwy. 14 bridge	2.9	124	126	6.7	6.8	12.9	12.9	7.0	6.4
5	Vermilion River at Bancker Ferry Crossing	5.8	143	145	6.6	6.7	13.2	13.2	5.3	5.2
6	Vermilion River, 1/2 mile north of Intracoastal Waterway	1.6	250	287	6.7	6.7	13.6	13.8	5.2	5.3
7	Vermilion River, 1/2 mile south of Intracoastal Waterway	3.9	1,880	1,600	6.7	6.7	13.2	13.2	8.7	8.4
8	Vermilion River, 2 miles south of Intracoastal Waterway, in Little Vermilion Bay	1.0	ND[1]	1,630	ND[1]	7.0	ND[1]	13.8	ND[1]	8.6
9	Vermilion River, 5 miles south of Intracoastal Waterway, at Vermilion Bay	2.0	6,560	6,360	7.7	8.0	12.8	13.7	9.6	10.6

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[1] Depth of water at this site was not sufficient for measurements to be taken at both water surface and channel bottom.

Table A5. Measured trace-element concentrations and physical and chemical properties for bottom material and selected water analyses for Calcasieu River (Calcasieu-Mermentau River Basin), September 17-18, 1991

[Hwy., Highway; µm, micrometers; m^2/g, square meters per gram; ND, no data]

Site number and description	Milligrams per kilogram										Weight percent			
	Antimony	Arsenic	Chromium	Cobalt	Copper	Lead	Mercury	Nickel	Selenium	Zinc	Aluminum	Iron	Manganese	Titanium
1 Calcasieu River, 2 miles upstream from Interstate Hwy. 10	0.3	2.2	20	6	7	24	0.07	6	0.4	26	3.2	1.0	125	0.25
2 Calcasieu River at Lake Charles	.6	5.8	63	12	26	40	.19	16	.7	81	6.4	2.7	326	.41
3 Calcasieu River at Prien Lake	.3	1.7	15	5	8	19	.11	6	.2	27	2.6	.7	79	.19
4 Calcasieu River, 2 miles downstream from Prien Lake	.5	5.2	61	12	34	45	.47	20	.5	80	6.3	2.7	422	.35
5 Calcasieu River, 1 mile north of the Intracoastal Waterway	.5	5.5	45	11	18	67	.13	15	.4	68	5.6	2.5	296	.34
6 Intracoastal Waterway at Devil's Elbow	.4	5.2	44	12	14	22	.15	16	.5	62	5.8	2.3	197	.34
7 Calcasieu River, 4 miles downstream from the Intracoastal Waterway	.4	4.6	42	9	15	24	.15	18	.4	61	5.8	2.2	220	.34
8 Calcasieu Lake, ship channel, 8 miles south of the Intracoastal Waterway	.4	5.6	44	12	15	22	.11	16	.3	63	6.1	2.4	469	.34
9 Calcasieu Lake, 8 miles north of the outlet into the Gulf of Mexico	.5	9.4	50	12	14	22	.07	30	.2	84	6.6	3.3	602	.29
10 Calcasieu River at outlet into the Gulf of Mexico	.5	7.3	62	13	17	26	.04	36	.3	87	7.4	3.9	650	.35

Table A5. Measured trace-element concentrations and physical and chemical properties for bottom material and selected water analyses for Calcasieu River (Calcasieu-Mermentau River Basin), September 17-18, 1991—Continued

	Weight percent			Percentage of sample with grain size less than						Milligrams per kilogram				
Site number and description	Loss on ignition	Total organic carbon	Other organic material	2 µm	16 µm	63 µm	125 µm	Mean grain size (µm)	Surface area (m^2/g)	$Fe.MnO_2$	MnO_2	$Fe.Fe_2O_3$	Ex.Fe	Ex.Mn
1 Calcasieu River, 2 miles upstream from Interstate Hwy. 10	5.0	1.5	3.5	1	19	36	53	63	5.9	410	6	670	3,200	90
2 Calcasieu River at Lake Charles	9.7	2.0	7.7	10	28	82	90	29	17.8	440	17	1,400	8,400	8,400
3 Calcasieu River at Prien Lake	3.3	.8	2.4	1	12	29	59	69	4.2	160	5	250	2,700	2,700
4 Calcasieu River, 2 miles downstream from Prien Lake	7.4	1.5	5.8	6	40	79	90	30	22.3	830	75	2,100	8,300	8,300
5 Calcasieu River, 1 mile north of the Intracoastal Waterway	6.9	1.4	5.5	15	59	73	87	37	18.3	730	31	1,800	8,300	8,300
6 Calcasieu River at Devil's Elbow	7.5	2.0	5.5	8	36	80	90	31	21.0	650	22	1,200	7,600	7,600
7 Calcasieu River, 4 miles downstream from the Intracoastal Waterway	5.8	1.3	4.6	27	52	81	96	26	16.8	570	23	1,400	6,400	6,400
8 Calcasieu Lake, ship channel, 8 miles south of the Intracoastal Waterway	5.2	.8	4.4	12	46	75	97	26	19.0	420	24	970	3,300	3,300
9 Calcasieu Lake, 8 miles north of the outlet into the Gulf of Mexico	4.5	.4	4.1	27	60	76	89	26	37.2	660	52	1,200	4,000	4,000
10 Calcasieu River at outlet into the Gulf of Mexico	4.9	.7	4.2	4	15	71	94	42	28.4	240	28	860	5,300	5,300

Table A5. Measured trace-element concentrations and physical and chemical properties for bottom material and selected water analyses for Calcasieu River (Calcasieu-Mermentau Basin), September 17-18, 1991—Continued

Site number and description	Depth, in meters	Specific conductance, in microsiemens per centimeter		pH		Temperature, in degrees Celsius		Dissolved oxygen, in milligrams per liter	
		Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface
1 Calcasieu River, 2 miles upstream from Interstate Hwy. 10	1.8	3,300	1,140	6.4	6.4	28.9	29.9	4.6	4.6
2 Calcasieu River at Lake Charles	11.9	24,900	6,120	7.1	7.0	29.5	31.0	.1	6.3
3 Calcasieu River at Prien Lake	1.2	10,210	8,890	6.9	7.3	29.5	30.9	2.1	6.1
4 Calcasieu River, 2 miles downstream from Prien Lake	14.3	25,400	9,640	7.2	7.6	29.9	30.4	.8	6.7
5 Calcasieu River, 1 mile north of the Intracoastal Waterway	12.9	27,600	13,400	7.6	7.5	30.0	31.1	2.6	7.0
6 Calcasieu River at Devil's Elbow	12.0	19,700	11,900	7.3	7.5	30.3	31.6	2.5	6.9
7 Calcasieu River, 4 miles downstream from the Intracoastal Waterway	1.2	ND[1]	17,200	ND[1]	7.6	ND[1]	31.1	ND[1]	5.0
8 Calcasieu Lake, ship channel, 8 miles south of the Intracoastal Waterway	11.0	30,600	18,300	8.0	8.2	30.0	32.1	3.8	8.1
9 Calcasieu Lake, 8 miles north of the outlet into the Gulf of Mexico	13.7	41,700	30,800	8.1	8.3	29.3	30.1	3.4	5.7
10 Calcasieu River at outlet into the Gulf of Mexico	1.0	ND[1]	31,900	ND[1]	8.1	ND[1]	30.0	ND[1]	3.9

[1] Depth of water at this site was not sufficient for measurements to be taken at both water surface and channel bottom.

Table A6. Measured trace-element concentrations and physical and chemical properties for bottom material and selected water analyses for Sabine River (Sabine River Basin), March 30-31, 1992

[Hwy., Highway; µm, micrometers; m^2/g, square meters per gram; ND, no data]

	Site number and description	Milligrams per kilogram										Weight percent			
		Antimony	Arsenic	Chromium	Cobalt	Copper	Lead	Mercury	Nickel	Selenium	Zinc	Aluminum	Iron	Manganese	Titanium
1	Old River, 1/4 mile north of Nibletts Bluff	0.4	3.4	26	12	6	20	0.05	8	0.2	38	3.4	1.3	0.07	0.30
2	Sabine River, 2.5 miles south of Interstate Hwy. 10	.4	2.8	26	8	22	58	.02	7	.4	64	3.2	1.1	.02	.25
3	Sabine River, 4 miles south of Intracoastal Waterway	.5	11.6	52	11	18	23	.04	22	.4	65	5.8	3.5	.03	.36
4	Sabine River at extreme north end of Sabine Lake	.2	2.1	13	5	4	<1	.03	<1	<.1	22	2.1	.7	.01	.22
5	Sabine Lake, 5 miles from the north end of the lake and 4.5 miles east of Port Arthur, Tex.	.4	4.2	30	10	8	17	.03	11	.3	56	3.7	1.7	.03	.30
6	Sabine Lake, 3 miles north of the La. Hwy. 82 bridge	.3	5.4	31	10	8	18	.02	13	.1	55	4.3	1.9	.03	.26
7	Sabine Lake, 1/4 mile north of La. Hwy. 82 launch	.4	6.0	32	11	8	18	.02	8	.1	59	4.6	2.0	.04	.28
8	Sabine River, 5 miles south of La. Hwy. 82 launch	.5	10.0	68	14	17	32	.04	29	.3	91	6.7	3.3	.13	.33
9	Sabine River at confluence with Gulf of Mexico, in line with the coastline	.5	8.6	45	13	13	25	.03	24	.3	66	5.6	2.7	.09	.29

Table A6. Measured trace-element concentrations and physical and chemical properties for bottom material and selected water analyses for Sabine River (Sabine River Basin), March 30-31, 1992—Continued

	Weight percent			Percentage of sample with grain size less than						Milligrams per kilogram				
Site number and description	Loss on ignition	Total organic carbon	Other organic material	2 µm	16 µm	63 µm	125 µm	Mean grain size (µm)	Surface area (m^2/g)	$Fe.MnO_2$	MnO_2	$Fe.Fe_2O_3$	Ex.Fe	Ex.Mn
1 Old River, 1/4 mile north of Nibletts Bluff	5.1	1.5	3.6	5	34	50	55	125	12.2	680	62	1,300	4,500	380
2 Sabine River, 2.5 miles south of Interstate Hwy. 10	7.0	2.6	4.3	3	18	38	53	147	12.9	280	16	500	3,000	640
3 Sabine River, 4 miles south of Intracoastal Waterway	5.5	1.4	5.3	3	35	87	92	25	37.7	340	33	2,700	10,000	160
4 Sabine River at extreme north end of Sabine Lake	1.8	.3	1.5	1	3	12	38	116	3.2	310	9	980	2,800	210
5 Sabine Lake, 5 miles from the north end of the lake and 4.5 miles east of Port Arthur, Tex.	3.4	.7	2.7	2	14	51	88	47	10.2	360	24	2,900	6,700	85
6 Sabine Lake, 3 miles north of the La. Hwy. 82 bridge	4.6	.5	4.1	5	15	39	74	61	5.0	470	34	3,200	7,100	280
7 Sabine Lake, 1/4 mile north of La. Hwy. 82 launch	3.1	.6	2.5	4	16	48	89	51	18.3	480	32	3,200	7,400	270
8 Sabine River, 5 miles south of La. Hwy. 82 launch	6.8	1.4	5.4	4	19	78	94	35	32.5	690	220	4,100	11,000	1,500
9 Sabine River at confluence with Gulf of Mexico, in line with the coastline	7.3	1.5	5.8	6	25	75	93	35	32.0	580	130	4,000	9,800	960

Table A6. Measured trace-element concentrations and physical and chemical properties for bottom material and selected water analyses for Sabine River (Sabine River Basin), March 30-31, 1992—Continued

Site number and description		Depth, in meters	Specific conductance, in microsiemens per centimeter		pH		Temperature, in degrees Celsius		Dissolved oxygen, in milligrams per liter	
			Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface
1	Old River, 1/4 mile north of Nibletts Bluff	11.5	134	136	6.6	6.6	18.1	18.1	7.8	7.9
2	Sabine River, 2.5 miles south of Interstate Hwy. 10	11.2	136	140	6.5	6.5	18.1	18.2	7.3	7.1
3	Sabine River, 4 miles south of Intracoastal Waterway	8.4	153	160	6.5	6.6	18.5	21.7	7.6	8.6
4	Sabine River at extreme north end of Sabine Lake	.8	ND[1]	163	ND[1]	6.6	ND[1]	18.6	ND[1]	7.4
5	Sabine Lake, 5 miles from the north end of the lake and 4.5 miles east of Port Arthur, Tex.	2.7	285	274	6.5	6.5	19.3	19.3	8.2	8.2
6	Sabine Lake, 3 miles north of the La. Hwy. 82 bridge	2.4	297	297	7.3	7.4	18.8	18.9	8.7	8.8
7	Sabine Lake, 1/4 mile north of La. Hwy. 82 launch	2.0	338	308	6.9	7.1	18.5	19.5	8.5	8.6
8	Sabine River, 5 miles south of La. Hwy. 82 launch	6.7	3,600	814	7.2	7.2	18.6	19.2	7.4	8.0
9	Sabine River at confluence with Gulf of Mexico, in line with the coastline	3.8	2,800	1,270	7.0	7.1	19.0	19.4	8.2	8.5

[1] Depth of water at this site was not sufficient for measurements to be taken at both water surface and channel bottom.