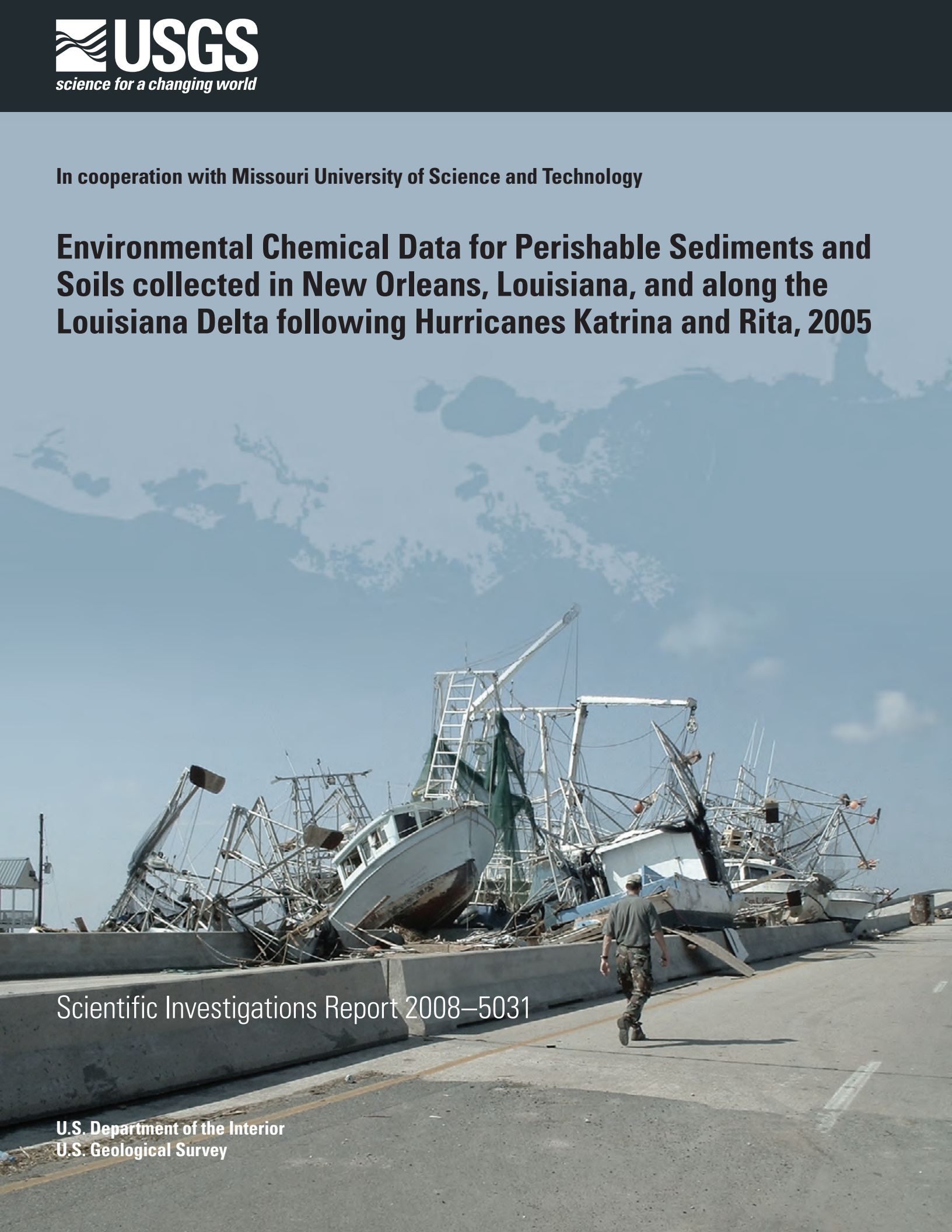


In cooperation with Missouri University of Science and Technology

# Environmental Chemical Data for Perishable Sediments and Soils collected in New Orleans, Louisiana, and along the Louisiana Delta following Hurricanes Katrina and Rita, 2005



Scientific Investigations Report 2008–5031

**Cover and Text Photographs.** The aftermath of Hurricanes Katrina and Rita, 2005. Photographs by Emmitt Witt, III and David Shaver, U.S. Geological Survey and Jianmin Wang, Missouri University of Science and Technology.

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By Emmitt C. Witt III, Honglan Shi, Krista A. Karstensen, Jianmin Wang, and  
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In cooperation with Missouri University of Science and Technology

Scientific Investigations Report 2008–5031

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Suggested citation:

Witt, E.C., Shi, Honglan, Karstensen, K.A., Wang, Jianmin, and Adams, C.D., 2008, Environmental chemical data for perishable sediments and soils collected in New Orleans, Louisiana, and along the Louisiana Delta following Hurricanes Katrina and Rita, 2005: U.S. Geological Survey Scientific Investigations Report 2008-5031, 56 p.



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## Conversion Factors and Datums

### SI to Inch/Pound

Multiply	By	To obtain
Length		
nanometer	3.937e-8	inch (in.)
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
Area		
square meter (m <sup>2</sup> )	0.0002471	acre
square kilometer (km <sup>2</sup> )	247.1	acre
square centimeter (cm <sup>2</sup> )	0.001076	square foot (ft <sup>2</sup> )
square meter (m <sup>2</sup> )	10.76	square foot (ft <sup>2</sup> )
square meter (m <sup>2</sup> )	3.861022e <sup>-7</sup>	square mile (mi <sup>2</sup> )
square centimeter (cm <sup>2</sup> )	0.1550	square inch (ft <sup>2</sup> )
square hectometer (hm <sup>2</sup> )	0.003861	section (640 acres or 1 square mile)
hectare (ha)	0.003861	square mile (mi <sup>2</sup> )
square kilometer (km <sup>2</sup> )	0.3861	square mile (mi <sup>2</sup> )
Volume		
cubic meter (m <sup>3</sup> )	0.0008107	acre-foot (acre-ft)
cubic meter (m <sup>3</sup> )	35.31	cubic foot (ft <sup>3</sup> )
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	0.2642	gallon (gal)
liter (L)	61.02	cubic inch (in <sup>3</sup> )
microliter (μL)	0.0338x10 <sup>-3</sup>	ounce, fluid
milliliter (mL)	0.06102	cubic inch (in <sup>3</sup> )
milliliter (mL)	0.0000353	cubic foot (ft <sup>3</sup> )
Flow rate		
liter per minute (L/min)	0.0005886	cubic foot per second (ft <sup>3</sup> /s)
meter per hour (m/hr)	3.281	foot per hour (ft/hr)
kilometer per hour (km/hr)	0.6214	mile per hour (mi/hr)
Mass		
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
milligram (g)	3.53x10 <sup>-5</sup>	ounce
Concentration		
microgram per liter (μg/L)	1	part per billion (ppb)
milligram per liter (mg/L)	1	part per million (ppm)
milligram per kilogram (mg/kg)	1	part per million (ppm)



Temperature in degrees Celsius ( $^{\circ}\text{C}$ ) may be converted to degrees Fahrenheit ( $^{\circ}\text{F}$ ) as follows:

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32$$

Temperature in degrees Fahrenheit ( $^{\circ}\text{F}$ ) may be converted to degrees Celsius ( $^{\circ}\text{C}$ ) as follows

$$^{\circ}\text{C}=(^{\circ}\text{F}-32)/1.8$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ( $\mu\text{S}/\text{cm}$  at  $25^{\circ}\text{C}$ ).

Concentrations of chemical constituents in water are given either in milligrams per liter ( $\text{mg}/\text{L}$ ) or micrograms per liter ( $\mu\text{g}/\text{L}$ ).

### Abbreviated Water-Quality Units

$\mu\text{g}/\text{kg}$	microgram per kilogram
$\mu\text{g}/\text{L}$	microgram per liter
$\text{mg}/\text{kg}$	milligram per kilogram
$\text{mg}/\text{L}$	milligram per liter
$\text{mL}/\text{min}$	milliliter per minute
M	molar

### Abbreviations and Acronyms

As	arsenic
BTEX	benzene, toluene, ethylene, and xylene
Cd	cadmium
Cr	chromium
Cu	copper
CVAPS	cold vapor atomic fluorescence spectroscopy
DRC	dynamic reaction cell
GC	gas chromatograph
GC-ECD	gas chromatograph-electron capture detection
GC-MS	gas chromatograph-mass spectrometry

GFAA	graphite furnace atomic absorption
Hg	mercury
HHMSSL	human health medium-specific screening level
ICP-MS	inductively-coupled plasma-mass spectrometry
LFB	laboratory fortified blanks
LFS	laboratory fortified samples
LRB	laboratory reagent blank
MDL	method detection level
µm	micrometer
Missouri S & T	Missouri University of Science and Technology
NGS	National Geochemical Survey
Pb	lead
PCB	polychlorinated biphenyl
ppb	parts per billion
psi	pounds per square inch
RCF	relative centrifugal force
RPD	relative percent difference
rpm	revolutions per minute
SC	Sklar Primacs
TDI	tolerable daily intake
TOC	total organic carbon
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
UTC	Universal Time Code
V	vanadium
WHO	World Health Organization

# Environmental Chemical Data for Perishable Sediments and Soils collected in New Orleans, Louisiana, and along the Louisiana Delta following Hurricanes Katrina and Rita, 2005

By Emmitt C. Witt III<sup>1</sup>, Honglan Shi<sup>2</sup>, Krista A. Karstensen<sup>1</sup>, Jianmin Wang<sup>2</sup>, and Craig D. Adams<sup>2</sup>

## Abstract

In October 2005, nearly one month after Hurricanes Katrina and Rita, a team of scientists from the U.S. Geological Survey and the Missouri University of Science and Technology deployed to southern Louisiana to collect perishable environmental data resulting from the impacts of these storms. Perishable samples collected for this investigation are subject to destruction or ruin by removal, mixing, or natural decay; therefore, collection is time-critical following the depositional event.

A total of 238 samples of sediment, soil, and vegetation were collected to characterize chemical quality. For this analysis, 157 of the 238 samples were used to characterize trace element, iron, total organic carbon, pesticide, and polychlorinated biphenyl concentrations of deposited sediment and associated shallow soils. In decreasing order, the largest variability in trace element concentration was detected for lead, vanadium, chromium, copper, arsenic, cadmium, and mercury. Lead was determined to be the trace element of most concern because of the large concentrations present in the samples ranging from 4.50 to 551 milligrams per kilogram (mg/kg). Sequential extraction analysis of lead indicate that 39.1 percent of the total lead concentration in post-hurricane sediment is associ-

ated with the iron-manganese oxide fraction. This fraction is considered extremely mobile under reducing environmental conditions, thereby making lead a potential health hazard. The presence of lead in post-hurricane sediments likely is from redistribution of pre-hurricane contaminated soils and sediments from Lake Pontchartrain and the flood control canals of New Orleans. Arsenic concentrations ranged from 0.84 to 49.1 mg/kg. Although Arsenic concentrations generally were small and consistent with other research results, all samples exceeded the U.S. Environmental Protection Agency's Human Health Medium-Specific Screening Level of 0.39 mg/kg. Mercury concentrations ranged from 0.02 to 1.30 mg/kg. Comparing the mean mercury concentration present in post-hurricane samples with regional background data from the U.S. Geological Survey National Geochemical Dataset, indicates that mercury concentrations in post-hurricane sediment generally are larger. Sequential extraction analysis of 51 samples for arsenic indicate that 54.5 percent of the total arsenic concentration is contained in the extremely mobile iron-manganese oxide fraction. Pesticide and polychlorinated biphenyl Arochlor concentrations in post-hurricane samples were small. Prometon was the most frequently detected pesticide with concentrations ranging from 2.4 to 193 micrograms per kilogram ( $\mu\text{g}/\text{kg}$ ). Methoxychlor was present in 22 samples with a concentration ranging from 3.5 to 3,510  $\mu\text{g}/\text{kg}$ . Although methoxychlor had the largest detected pesticide concentration, it was well below the U.S. Environmental Protection Agency's High-Priority Screening Level for residential soils. Arochlor congeners were not detected for any sample above the minimum detection level of 7.9  $\mu\text{g}/\text{kg}$ .

<sup>1</sup>U.S. Geological Survey.

<sup>2</sup>Missouri University of Science and Technology.



## Introduction

The 2005 storm season was the most devastating in Gulf Coast history. Hurricane Katrina came ashore on August 29, damaging the flood-control infrastructure of New Orleans and the Louisiana Delta with its storm surge and high winds. The resulting flood waters inundated more than 141,000,000 square meters (m<sup>2</sup>) in New Orleans destroying homes, businesses, and supporting municipal infrastructure (Adams and others, 2007). Additionally, the flood waters brought nearly 708,000 m<sup>3</sup> of sediment that was deposited in New Orleans. Less than one month later, Hurricane Rita passed through western Louisiana causing more flooding and sediment deposition to the already devastated area.

The origin of the sediment deposited in New Orleans primarily is from the channel systems that are designed to drain the city and Lake Pontchartrain. These sediments likely are to have accumulated large concentrations of trace elements and organic compounds from years of municipal and industrial drainage. The mixing of these sediments with debris from the hurricane-damaged infrastructure may be responsible for increases in trace element concentration.

A team of U.S. Geological Survey (USGS) and Missouri University of Science and Technology (Missouri S&T) scientists deployed to the affected region from October 6 to 18, 2005, to collect perishable environmental and engineering data (Witt and others, 2006; Luna and others, 2006; Chen and others, 2006). The team was responsible for collecting many photographs and videos of the damage to infrastructure and flood control systems, as well as samples of the deposited sediments and associated soils. For the purpose of this report, sediment is defined as a solid material that has settled from a state of suspension in a liquid, and soil as the unconsolidated mineral or organic material on the surface of the earth that has been subjected to and shows effect of genetic and environmental factors of climate (including water and temperature effects) and macro- and microorganisms, conditioned by relief, acting on parent material during a specific time period (Neuendorf and others, 2005).

This report presents the chemical data and quality assurance information for 157 soil and sediment samples collected in New Orleans and the Louisiana Delta following the two storms. The physical devastation associated with the wrath of Hurricanes Katrina and Rita is not limited to scattered debris and structural damage; to the contrary, some of the most harmful effects of the storms lay beneath the surface. The collection, analytical methods, and results of this investigation serve to expose the potential problems and health risks associated with the post-storm sediment chemistry of New Orleans and the Louisiana Delta. Additionally, the results will serve as a planning tool for residents, developers, and debris removal teams as they prepare to make this region habitable once more.

## 2005 Hurricane Season

The 2005 storm season was one of the worst and longest in recorded history. Thirty-one major storms occurred in the Atlantic-Caribbean-Gulf region during 2005; of those, 27 were given names by the National Hurricane Center validating the intensity and potentially catastrophic effects of these storms on land and sea. The official record of storms, by intensity, that occurred during the 2005 season included 1 subtropical depression, 1 subtropical storm, 2 tropical depressions, 12 tropical storms, and 15 hurricanes (U.S. National Oceanic and Atmospheric Administration, 2007). The storm season began with tropical storm Arlene on June 8 to 13, 2005, which made landfall on the Florida panhandle causing moderate damage. The season ended with tropical storm Zeta on December 30, 2005 to January 6, 2006. Tropical storm Zeta did not make landfall, but it was the second recorded storm to occur that late in the year and to continue to the next calendar year (Knabb and Brown, 2006). Hurricanes Katrina and Rita made landfall nearly one month apart during the peak of hurricane season within 161 kilometers (km) of each other. The damage these two storms caused was unprecedented, and cleanup and rebuilding presently (2007) are still occurring.

## Hurricane Katrina

Hurricane Katrina was the first storm to impact southern Louisiana. With sustained winds of 60 km/hour, Katrina initially was categorized as Tropical Depression 12 when spotted on August 23, 2005, over the Bahamas Islands (National Oceanic and Atmospheric Administration, 2005). By August 24, 2005, the storm had grown in intensity and was upgraded by the National Hurricane Center as Tropical Storm Katrina. The storm further intensified as it approached the Florida coast and was upgraded to Category I hurricane status. Katrina made landfall on the southern tip of Florida about 100 km north of Key West, with sustained winds of about 115 kilometers per hour (km/hr). The hurricane quickly moved to the Gulf of Mexico and gradually intensified over the next 5 days before making landfall at 7 a.m. Central Standard Time August 29, 2005, between Port Sulphur, Louisiana, and the Empire/Buras, Louisiana, area (National Oceanic and Atmospheric Administration, 2005) (fig. 1). Initially, Katrina was reported to be a Category 4 storm when it made landfall, but a post-storm analysis by the National Hurricane Center indicates the storm actually was a Category 3 with sustained winds of 180 km/hr (Knabb and others, 2006).

The impact of Hurricane Katrina on the Delta region was enormous. The levees that protected the narrow strip of land from floods failed after receiving an extensive pounding from waves and wind. Homes, vehicles, boats, businesses, schools, and cemeteries were destroyed and scattered around the Delta's limited landscape (figs. 2 and 3). The salt water inflow from the Gulf of Mexico killed many of the mature fruit orchards of the lower Delta. The torrential flow of water



Base from Environmental Systems Research Institute digital data, 1983

Hurricane track data from the National Oceanic Atmospheric Administration National Hurricane Center, 2006 and the U.S. Census Bureau

**Figure 1.** National Hurricane Center storm track for Hurricanes Katrina and Rita, 2005.

dislodged many fuel storage tanks and ruptured those that did not become dislodged, causing the contents to be released throughout the Delta region. Large oil slicks were observed where water crested on the levees.

Hurricane Katrina made its second and final landfall a few hours later near the Louisiana/Mississippi border. The storm weakened slightly with sustained surface winds of 170 km/hr. As the center of the eye of the storm made its clos-

est approach [20 miles (mi)] to the east of downtown New Orleans, it maintained Category 3 intensity (Knabb and others, 2006a). The strongest winds corresponding to this intensity likely were present only over water to the east of the eye of the hurricane (Knabb and others, 2006a); therefore, most of the city of New Orleans probably experienced sustained surface winds of Category 1 or 2 strength. The eye of the storm was east of New Orleans, and the storm surge associated with the



**Figure 2.** Destruction inflicted by Hurricane Katrina along the Louisiana Delta. (photographs by Emmitt Witt and David Shaver, U.S. Geological Survey).

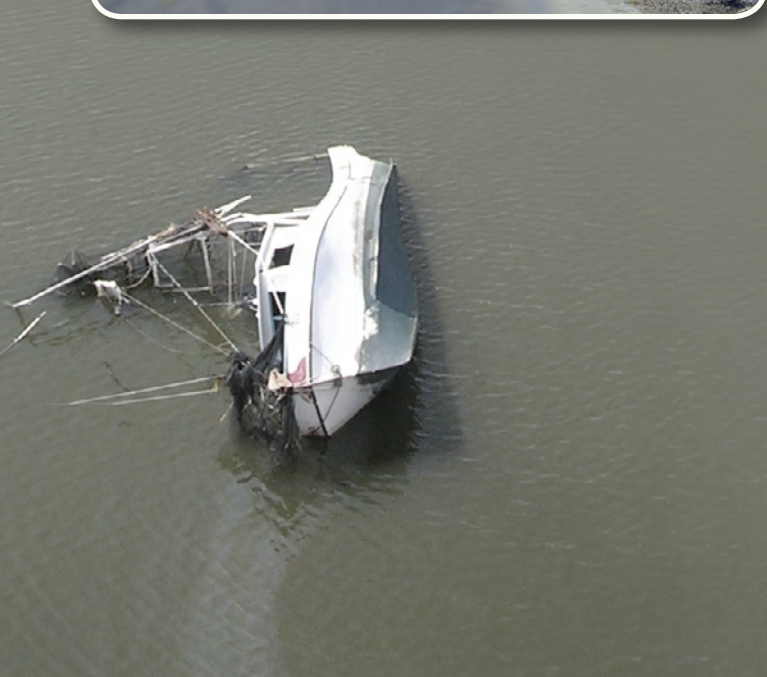




Figure 3. The destructive force that moving debris had on homes and property following levee failure in New Orleans, Louisiana. (photographs by Emmitt Witt and David Shaver, U.S. Geological Survey).



levee failures in the city was highest to the east of the path of Hurricane Katrina. Storm surge data indicate water levels of 5 to 6 meters (m) occurred in eastern New Orleans, St. Bernard Parish, and Plaquemines Parish; the surge was 3 to 4 m in western New Orleans along the southern shores of Lake Pontchartrain (Knabb and others, 2006a). The highest surge associated with Hurricane Katrina was recorded in Mississippi (Charles Demas, U.S. Geological Survey Louisiana Water Science Center, written commun., 2007)

The substantial storm surge exceeded the limits of the New Orleans flood control system the day of landfall. Storm surge overtopped large sections of the levees east of New Orleans, in Orleans Parish and St. Bernard Parish. A substantial amount of water was pushed up the Intercoastal Waterway and into the Industrial Canal. Breaches occurred during the early morning of August 29, 2005, along the Industrial Canal east of downtown New Orleans, the London Avenue Canal north of downtown New Orleans, and the 17th Street Canal northwest of downtown. These breaches led to the flooding of about 80 percent of the City completely swallowing homes in some areas. At and near the breached levees, the damage to structures and personal property was enormous (fig. 3). The water that entered the City was heavily laden with sand and silt transported from the canals and Lake Pontchartrain. The water and sediment was further mixed with the debris created by the damaged flood-control system, and deposited throughout the affected area (fig. 3).

## Hurricane Rita

Hurricane Rita began as a tropical depression on September 18, 2005, at about 1800 Universal Time Code (UTC) approximately 40 km east-southeast of the island of Mayaguana in the southeastern Bahamas (Knabb and others, 2006b). By September 20, tropical storm Rita became Hurricane Rita, attaining an intensity of Category 2. Hurricane Rita passed about 65 km south of Key West, Florida, and continued to gain strength as it moved through the Gulf of Mexico. The storm reached peak strength at Category 5 on September 22, then began to lose strength before reaching southwestern Louisiana just east of Sabine Pass on September 23 (fig. 1). Hurricane Rita weakened substantially to a Category 3 after making landfall. By 1200 UTC September 24, the storm was downgraded to a tropical storm soon after passing Beaumont, Texas.

Hurricane Rita devastated entire communities in coastal areas of southwestern Louisiana. Almost every structure in these areas was destroyed, and some were completely swept away. Several miles inland from the Gulf along Calcasieu Lake, numerous homes in the town of Grand Lake were damaged or destroyed. Many parts of the Lake Charles area suffered substantial flood damage, including the downtown area and some surrounding residential communities. Storm surge was a significant factor in property loss causing damage to homes and businesses in eastward, low-lying areas along the entire coast of Louisiana (Knabb and others, 2006b).

The USGS deployed 47 pressure transducers at 33 sites before the storm to monitor the timing, extent, and magnitude of the surge related to flooding. Based on storm surge data collected from McGee and others, 2006, the lasting impact on New Orleans, although not as severe as Hurricane Katrina, was the prolonging of flooding and sediment disposition.

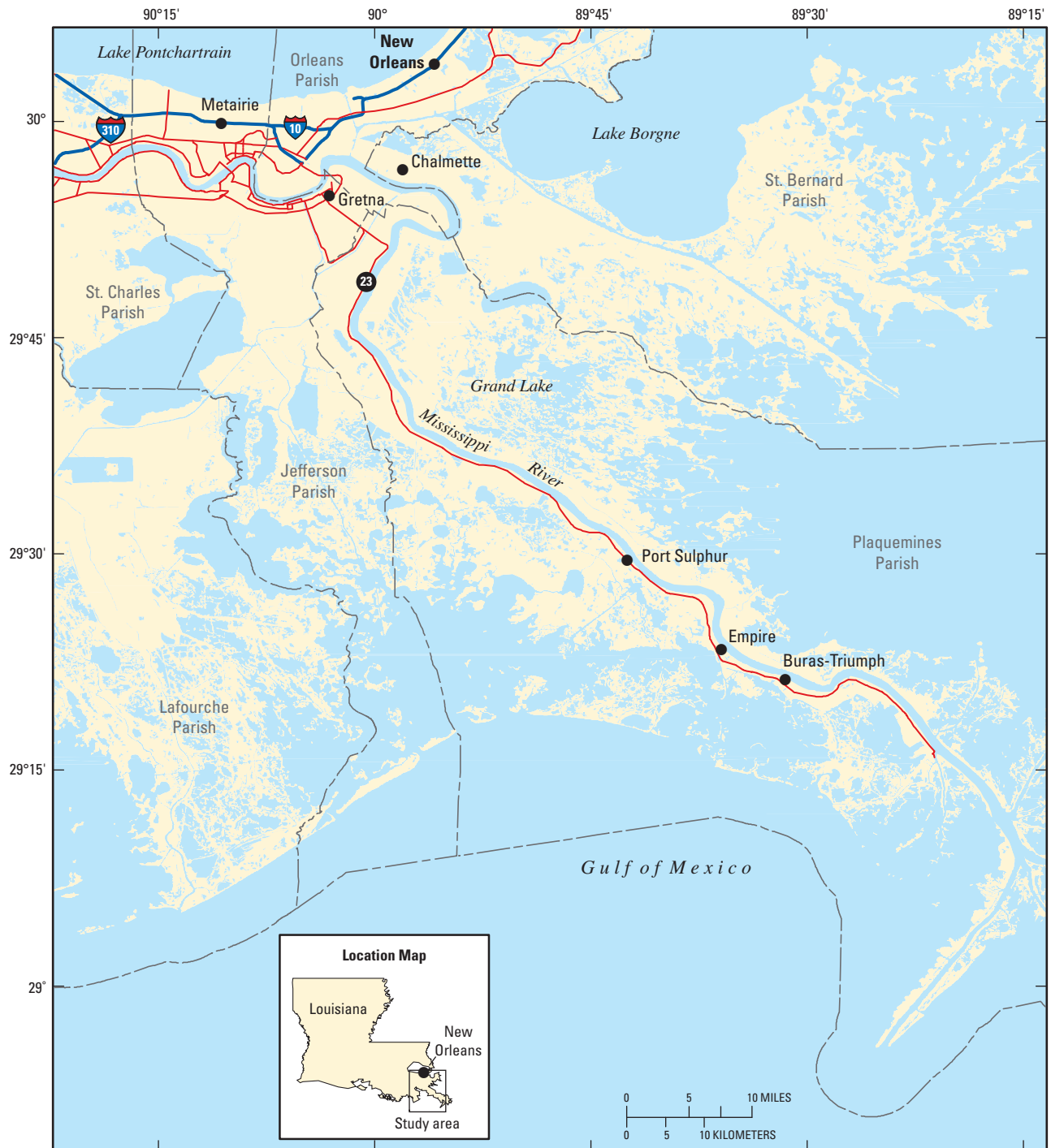
## Study Area Description

The study area includes the intersection of the southern shoreline of Lake Pontchartrain and extends southward to the 'bird foot' Delta that extends into the Gulf of Mexico (fig. 4). Samples collected in New Orleans represented the entire flood-impacted area, in addition to areas that received hurricane damage but no flood waters. Access to this area one month after the storm events was limited because of the large amount of debris scattered throughout the region. Most samples were collected in visibly impacted areas near homes, businesses, along road ways, or from the tops of and beneath automobiles. The sediment deposited in New Orleans after the storms could have come from a variety of sources including Lake Pontchartrain, the flood control canals, regional marshes, suspended soils that were in the city before the flooding, as well as other tributary channels in the region with Mississippi River drainage origins.

To mitigate flood hazards in a city whose average elevation is several feet below sea level, most of the stormwater runoff that accumulates in New Orleans is pumped to nearby Lake Pontchartrain. During normal conditions, stormwater is collected by an extensive system of canals and is discharged into the lake via drainage pumps and open surface drainage canals that redirect the runoff into the lake. The primary suspected source of pollution in Lake Pontchartrain is the pumped urban stormwater runoff that is discharged to the area (Carnelos and others, 2007). When Hurricanes Katrina and Rita struck New Orleans, the massive precipitation events overwhelmed the levees, canals, and drainage pumps, inundating the entire city. The floodwaters of Lake Pontchartrain redistributed many of the pollutants including pathogens, nutrients, and solids that had been pumped into the lake from previous precipitation events.

From a climatological perspective, the amount of rainfall and runoff this area receives has a substantial affect on the chemistry of the dispositioned sediments; thus, storm-water drainage is likely to contain a wide variety of urban contaminants. New Orleans is known for its large lead concentration in soils. Before Hurricanes Katrina and Rita, a program was underway to mitigate whole-body contact by children with New Orleans soils (Mielke and others, 2007). The background presented herein will facilitate analysis of these data by USGS and other research institutions in the future.





Base from the Louisiana Oil Spill Coordinator's Office, 2000  
Horizontal coordinate information referenced to the  
North American Datum of 1983 (NAD 83)

**Figure 4.** Generalized map of the study area.

## Method of Collection and Analysis

### Sample Collection

From October 6 to 18, 2005, 238 sediment, soil, and other samples were collected in New Orleans and along Highway 23 on the Louisiana Delta (fig. 5). The Missouri S&T Environmental Research Laboratory analyzed 46 of 203 soil and sediment samples for a preliminary investigation; those were not reanalyzed for this study because too little sample material remained (Adams and others, 2007). Thirty-five samples that were not used in this analysis include reference duplicates, oil-stained vegetation, soil samples from known oil spillage sites (targeted sampling that does not represent the region), and road surfaces. This analysis included 157 samples that were considered to be an unbiased representation of perishable sediments and soils from the hurricane affected region.

Sample locations were selected to provide a cross section of residential, business, and industrial (refinery) areas. Sites included the 17th-Street Levee breach, at the Industrial Levee breach, neighborhoods of the Brookmoor District, and near refineries in eastern New Orleans along the Mississippi River. Samples were collected along Highway 23 south of New Orleans including Empire (near the location where the eye of Hurricane Katrina passed through on August 29, 2005) as well as sites a few miles beyond Venice, near the Gulf fishing fleet marina. Given the logistical difficulties with moving around the impacted area, a pre-planned sampling strategy could not be employed. Samples were collected where access was available and when permissions were obtained. In most cases, the team moved freely between the damaged regions, with little control by the municipal authorities, land and business owners, or the National Guard. Given the complexity of the sampling effort so soon after the event, this analysis makes the assumption that these data are distributed randomly for comparative purposes.

Two procedures were used for sample collection—a coring procedure and a surface ‘grab’ collection procedure. In the coring procedure, a 2-centimeter [(cm) (0.787-inch (in.))] diameter hand-held corer was used to collect a soil sample up to 4 in. deep. The corer is made of stainless steel and has a plastic container to hold the sample. In some cases where deposited sediments were thicker, a deeper (up to 8 in.) core sample was collected. Where using a coring tool was impractical, such as collecting samples from the tops of and beneath automobiles, sidewalks, and inside and outside structures, a simple ‘grab’ method was used. Grab samples were collected with either a wooden tongue depressor or a small garden shovel, then were placed in 60-milliliter (mL) amber glass vials with Teflon-lined caps. To prevent cross-contamination of samples during sample collection, all personnel wore disposable latex gloves. The instruments used for sample collection were cleaned between sample sites to the best standard possible with the limited amount of rinse water available under the complexity of the situation. It was assumed that

this method would not substantially affect the chemistry of the samples because the reporting levels were substantially above the parts per billion range. The samples were labeled and the vials immediately double-bagged into plastic zip-lock bags and placed in the dark in a cooler. No preservatives were added to samples. Samples were kept as close to 4 degrees Celsius (°C) as possible and in the dark until analysis could be performed at the Missouri S&T Environmental Research Center Laboratory. Photographs of typical sample collection sites are shown in figure 6.

### Laboratory Analysis

Samples were analyzed beginning in October 2006 at the Missouri S&T, Environmental Research Center Laboratory for moisture, pH, single- and sequentially-digested concentrations (hereinafter referred to as “extraction”) of the trace elements V, Cr, Cu, Cd, Pb, As, and Hg, the major metallic element iron, pesticides, and polychlorinated biphenyls (PCBs). Analysis for total organic carbon was done at the University of Minnesota Soil Testing and Research Analytical Laboratory.

The chemicals and supplies used for analysis include certified grade magnesium chloride, sodium acetate, hydroxylamine hydrochloride, ammonium acetate, and anhydrous sodium sulfate; all were purchased from Fisher Scientific. Trace element grade nitric acid, hydrochloric acid, and hydrogen peroxide also were Fisher Scientific products. High performance liquid chromatography grade acetic acid, pesticide grade hexane, and acetone also were purchased from Fisher Scientific. The trace element standard solutions were purchased from Perkin Elmer. Certified reference standard samples of drinking water and waste water were purchased from High Purity Standards.

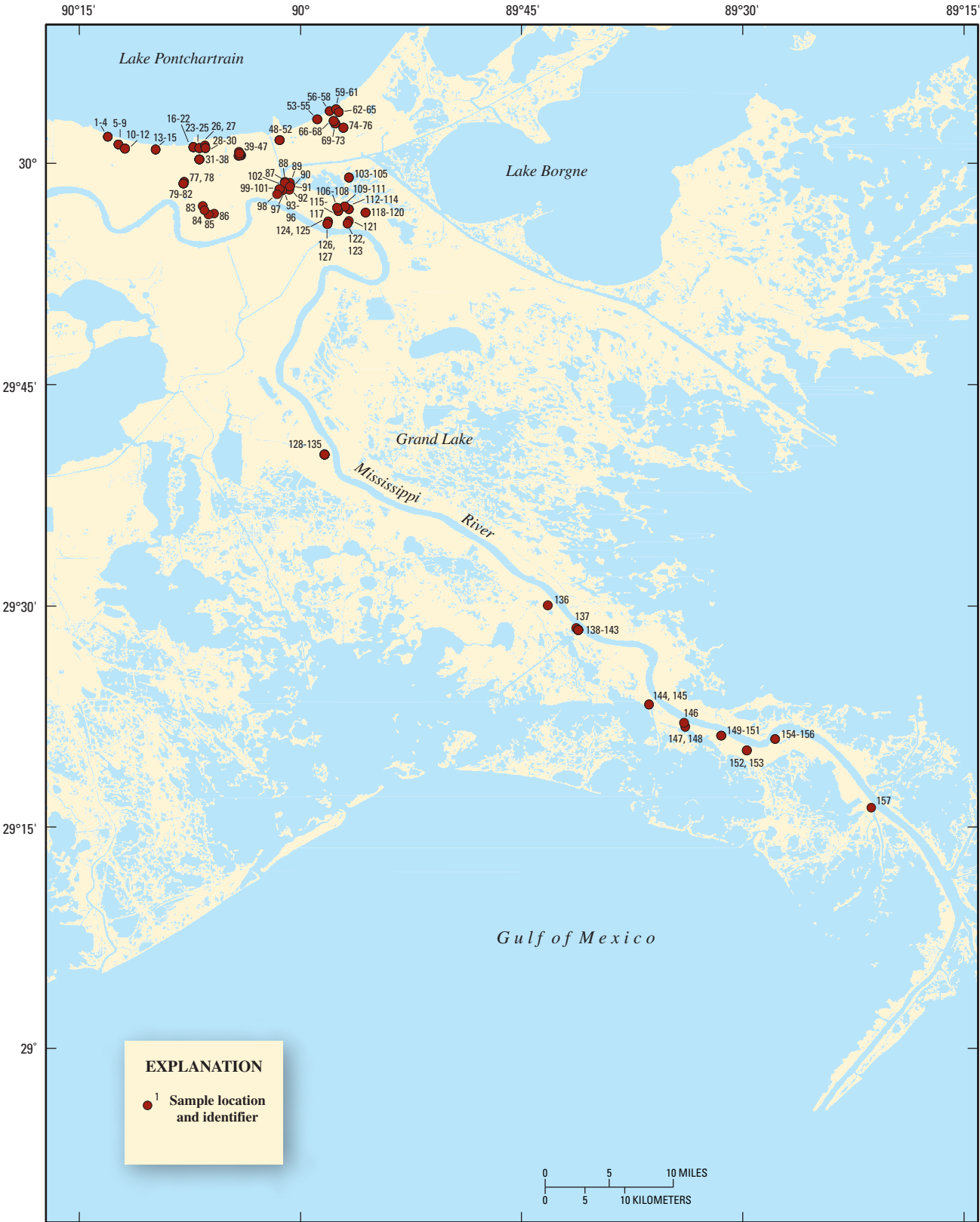
### Moisture, pH, and Total Organic Carbon

Moisture content was measured by weighing 1.00 gram (g) of soil sample into a pre-dried aluminum weighing dish. The sample was dried at 105 °C in an oven until constant weight was achieved. The difference of the wet weight and the dry weight of each sample is calculated as follows:

$$\% \text{ Moisture} = 100 \times (\text{weight of wet sample} - \text{weight of dry sample}) / \text{weight of wet sample} \quad (1)$$

A part of each sample was measured for pH by mixing 1.00 g of wet sample and 2.00 mL of de-ionized water in a test tube. The mixture was agitated to complete mixing, then centrifuged at 2,000 relative centrifugal force (RCF) for 5 minutes to precipitate the soil. The pH of the supernate was measured with a standard pH electrode and meter.

Total organic carbon (TOC) analysis for samples was performed by Soil Testing and Research Analytical Lab at University of Minnesota, 1902 Dudley Avenue, St. Paul, Minnesota. Total organic carbon was measured using a destructive quantitative technique involving dry combustion at high



Base from the Louisiana Oil Spill Coordinator's Office, 2000  
Horizontal coordinate information referenced to the  
North American Datum of 1983 (NAD 83)

Figure 5. Locations of 157 sample sites in the study area.



**Figure 6.** Soil and sediment collection areas (photographs by Emitt Witt and David Shaver, U.S. Geological Survey and Jianmin Wang, Missouri University of Science and Technology).

temperatures followed by measurement of the evolved carbon dioxide (CO<sub>2</sub>) (Tiessen and Moir, 1993). Before analysis, pH was measured to screen samples for the presence of calcium carbonate. If pH was greater than 7.8, then calcium carbonates are present. This suggests that part of the sample contains inorganic carbon that must be considered during quantification (McLean, 1982). As a quality assurance measure and to account for the presence of carbonates, a pH of 7.4 was used as a conservative threshold indicator that the sample must be conditioned to remove carbonates (U.S. Environmental Protection Agency, 2002b).

A Sklar Primacs (SC) carbon analyzer was used to measure total carbon following the total combustion of 200 to 300 milligram (mg) of sample in an oxygen rich atmosphere of a 1,050 °C furnace. The carbon-dioxide produced by the combustion is swept by an oxygen stream through a moisture trap, and then to the infrared detector that measures the amount of carbon dioxide produced. For samples with pH greater than 7.4, inorganic carbon is determined by adding 20 percent phosphoric acid to the sample, heating to 90 °C and then bubbling with oxygen to sweep the carbon dioxide produced to an infrared detector for quantification. For samples that contain carbonates, the organic carbon is calculated by subtracting the measured inorganic carbon from the measured total carbon.

### Trace Element and Iron Single Extraction

Samples were prepared for analysis using a microwave assisted acid-digestion following U.S. Environmental Protection Agency (USEPA) Method 3051A (1998). A Perkin Elmer Multiwave 3000 microwave digestion system was used to implement this procedure. Approximately 0.5 g of wet sample was added to a pre-acid cleaned microwave digestion vessel (for heavy duty 8-position rotor), then 9 mL trace element grade nitric acid (HNO<sub>3</sub>) and 3.00 mL of trace element grade hydrochloric acid (HCl) were added to the sample.

At the completion of the digestion process, the sample was transferred into a pre-acid cleaned 50 mL polypropylene centrifuge tube and diluted to 50.0 mL with de-ionized water. Appropriate dilutions were made for trace element analysis by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). All trace elements except mercury were analyzed according to USEPA Method 200.8 (U.S. Environmental Protection Agency, 1994). Arsenic, Cd, Cr, Cu, Pb, and V were analyzed using a Perkin Elmer Elan DRC-e ICP-MS. A Cyclonic spray chamber with Meinhard nebulizer and nickel cones was used and the samples were delivered at 1 milliliter per minute (mL/min) by a peristaltic pump. The radiated power was 1,500 watts. Argon flow rates for the plasma and auxiliary gas were 15.0 and 1.20 liters per minute (L/min) respectively. Quantitation was performed with an internal standard method. A multi-element internal standard mixture was used and was added continuously online. Arsenic as arsenate (AsO) was detected by Dynamic Reaction Cell (DRC) mode to eliminate the chloride interference from the HCl addition during acid digestion. The DRC reaction cell gas was oxygen.

Mercury concentrations in the digested samples were measured using USEPA Method 1631, revision E (U.S. Environmental Protection Agency, 2002a). A Tekran® Series 2600 Ultra-trace Mercury Analysis System (Tekran Inc., Toronto, Canada) was used to analyze the samples. The equipment uses a dual stage gold pre-concentration for mercury followed by Cold Vapor Atomic Fluorescence Spectroscopy (CVAFS) detection. The microwave acid-digested sample solutions were digested with 0.5 percent bromine chloride (BrCl) for 12 hours before analysis, which ensured that bromine chloride had enough time to oxidize all forms of mercury in the sample to Hg<sup>2+</sup>. The bromine chloride stock solution was prepared by dissolving 5.50 g potassium bromide and 7.50 g potassium bromate in 100 mL de-ionized water, and then slowly adding 400 mL of trace element grade hydrochloric acid under a fume hood. Both potassium bromide and potassium bromate were heated at 180 °C in a mercury-free oven for a period of 12 hours before bromine chloride stock solution preparation to negate any background mercury. After oxidation with bromine chloride and just prior to analysis, the samples were reduced sequentially with hydroxylamine hydrochloride (NH<sub>2</sub>OH·HCl) to destroy the free halogens present. NH<sub>2</sub>OH·HCl was prepared by weighing 75.0 g NH<sub>2</sub>OH·HCl and dissolving it into 250 mL de-ionized water. The solution was purified using a 3 percent stannous chloride (SnCl<sub>2</sub>) reducing solution and purged with ultra high purity argon for at least 2 hours to convert all the Hg<sup>2+</sup> to volatile elemental Hg(0). This was separated from the solution over a phase separator by mercury free ultra high purity argon carrier gas. The Hg(0) was then trapped on a gold coated sand trap, desorbed thermally, and moved through a cell of the CVAFS for detection.

Iron was measured by flame atomic absorption spectrometry using USEPA Method 7000A (1992; superseded by USEPA Method 7000B, 2007). The digested solutions were diluted 5 to 20 times with de-ionized water, then directly aspirated into an air-acetylene oxidizing flame of a Perkin Elmer model 3110 flame atomic absorption spectrometer. A single element hollow cathode iron lamp was used as a light source. Absorbance was determined at 248.3 nanometers (nm) with the slit set at 0.20 nanometer (nm). The iron concentration was obtained with an external calibration method within the linear calibration range [0.1 milligram per liter (mg/L)–20 mg/L].

### Trace Element and Iron Sequential Extraction

Sequential extraction of trace elements V, Cd, Cr, Cu, Pb, and As was done to evaluate the speciation of particulate-bound constituents. This analysis method is more time consuming and costly to conduct than the single extraction approach, but provides detailed information about the origin, mode of occurrence, biological and physiochemical availability, mobilization, and transport of trace elements in the environment. Mercury was not analyzed in the sequential extraction fraction because of the low levels of mercury observed in the single extraction analysis.

The sequential extraction procedure was modified from Tessier and others (1979) to include five measurable fractions: exchangeable, bound to carbonates, bound to Fe-Mn oxides, bound to organic matter, and residual. These five fractions were measured from a series of extractions from a single 0.50 g aliquot of sample. The extraction process for each fraction is described in the following sections.

#### Exchangeable Fraction (F1)

This fraction involves the trace elements complexed to clays, hydrated oxides, and humics. This fraction was extracted at room temperature for 1 hour with 5.00 mL of 1 molar (M) magnesium chloride (pH 7.0) under agitation on a shaker at low speed. The sample was centrifuged at 7,000 g for 40 minutes. The supernatant was transferred to a pre-acid cleaned sampler tube and analyzed for trace elements and iron. The residue was washed with 4 mL of de-ionized water, and separated from the wash by centrifuging for 40 minutes at 7,000 g. The washed residue is used for the next extraction procedure.

#### Bound to Carbonate Fraction (F2)

This fraction involves metals complexed with carbonate. The fraction was prepared using the residual from the F1 extraction, and adding 5.00 mL of a buffered 1 M sodium acetate solution (pH 5.0). The mixture was agitated for 5 hours at room temperature, separated from the residue, and analyzed for trace elements and iron. The remaining residue was washed and used for the next extraction procedure.

#### Iron and Manganese Oxides Fraction (F3)

The F3 fraction accounts for trace elements associated with iron and manganese oxides. Residue from the F2 is mixed with 10 mL of 0.04M  $\text{NH}_2\text{OH}\cdot\text{HCl}$  in 25 percent acetic acid (HOAc) and agitated for 6 hours at 96 °C. The mixture was centrifuged and the supernatant is analyzed for trace elements and iron. The residue is washed with de-ionized water, centrifuged, and used for the next extraction procedure.

#### Organic Matter Fraction (F4)

This fraction accounts for trace elements and iron associated with organic matter in the sample. The constituents are released from organic matter through oxidation. In this procedure, the F3 residue was mixed with 1.50 mL of 0.02 M  $\text{HNO}_3$  and 2.5 mL of 30 percent hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) and agitated for 2 hours at 85 +/- 2 °C. Then 1.50 mL more of 30 percent  $\text{H}_2\text{O}_2$  is added and agitated for 3 more hours at 85 +/- 2 °C. After the mixture has cooled to room temperature, 2.50 mL of 3.20 M ammonium acetate ( $\text{NH}_4\text{OAc}$ ) in 20 percent  $\text{HNO}_3$  and 2.00 mL de-ionized water was added and allowed to continue digestion for another 30 minutes. As with the previous fraction, the supernatant is analyzed for trace elements and iron, and the residue is washed with de-ionized water, centrifuged, and used in the next extraction procedure.

#### Residual Fraction (F5)

The remaining residue solid should contain mainly primary and secondary minerals that may hold trace metal elements within their crystal structure. These metal elements are not expected to be released in solution during a reasonable time span under the conditions normally encountered in nature (Tessier and others, 1979); therefore, a strong acid digestion as described in Method 3051A (U.S. Environmental Protection Agency, 1998) was used on the F4 fraction to extract the remaining trace elements.

An ICP-MS was used to measure all trace elements within all fractions with the exception of vanadium and chromium. The ICP-MS detection conditions were the same as those of the single extraction samples. Vanadium and chromium in the F3 (iron and manganese oxides fraction) were detected using graphite furnace atomic absorption (GFAA) spectrometry because matrix interference was encountered using the ICP-MS method. A Perkin Elmer Analyst 600 GFAA was used. The samples were diluted with 1 percent  $\text{HNO}_3$  before analysis. A cleaning reagent (0.2 percent Triton-X and 1 percent nitric acid in de-ionized water) was used to flush the inlet between each sample; the matrix modifier used was 0.015 mg of  $\text{Mg}(\text{NO}_3)_2$ . Vanadium and chromium were analyzed at 318.4 nm and 357.9 nm, respectively, with vanadium and chromium Hollow Cathode Lamps as light sources. The instrument was optimized and calibrated by following the manufacturer's instructions.

#### Pesticide and Polychlorinated Biphenyl Extraction

Pesticide and PCB were extracted simultaneously from soil samples by ultrasonic extraction using the modified USEPA Method 3550C (U.S. Environmental Protection Agency, 2000). Eight g of sample was added to a 40-mL glass vial, then 6 g of pre-heated anhydrous sodium sulfate was added to the vial. After mixing, 15 microliters ( $\mu\text{L}$ ) pentachloronitrobenzene (PCNB, 5 parts per million (ppm) in acetone) of surrogate was added. Before extraction, 17 mL of acetone/hexane (1:1) mixture was added. The sample was well mixed on a vortex mixer, then placed in an ultrasonic water bath and extracted for 20 minutes. The sample was centrifuged for 10 minutes at 1,000 revolutions per minute (rpm) with a clinical centrifuge and the supernatant was transferred into a graduated conical centrifuge tube. The residue was extracted for a second time with 13 mL of hexane/acetone mixture using the same procedure as the first extraction. Following the second extraction, the extractant was evaporated by a Turbo Vap LV Evaporator to 3.00 mL to increase the concentration. The final extract was dried with anhydrous sodium sulfate ( $\text{Na}_2\text{SO}_4$ ) and centrifuged to remove any particles before instrument analysis. The extracted sample was stored in an amber vial at 4 °C before analysis.

For this study, 20 samples per batch run were extracted; each batch run contained a laboratory reagent blank, a fortified reagent blank (reagent spike), a laboratory fortified sample

(sample spike), and a sample duplicate. An ultrasonic water bath instead of an ultrasonic probe was used to improve the efficiency of processing large sample batches. This extraction method was verified by performing a series of fortified reagent blank extractions and fortified sample extractions before sample extraction. The results of this verification are presented in the “Quality Assurance” section of this report.

### Gas Chromatograph-Electron Capture Detection

Gas Chromatograph Electron Capture Detection (GC-ECD) analysis was done using USEPA Method 8082 (U.S. Environmental Protection Agency, 1996). One mL of extracted sample was transferred into a gas chromatograph auto-sampler vial, then 5  $\mu$ L of 2,4,5,6-tetrachloro-m-xylene (TCX, 5.00 mg/L) in acetone), the internal standard, was added to make a final concentration of 25.0 micrograms per liter ( $\mu$ g/L). An Agilent model 6890 Gas Chromatograph (GC) with a micro-electron capture detector and a liquid auto-sampler was used for the analysis; two  $\mu$ L of sample was injected into the GC using the splitless mode. An Agilent HP-5 column [30.0 m x 0.32 millimeter (mm), 0.25-micrometer ( $\mu$ m) film thickness] was used for separation. The carrier gas used was high purity nitrogen at 16.0 pounds per square inch (psi) constant column head pressure. The inlet and detector temperatures were controlled at 225 °C and 300 °C, respectively. The oven gradient temperatures were set at 100 °C for 2 minutes, then increased to 160 °C for 15 degrees Celsius per minute (°C/minutes), followed by 5 °C/minute to 270 °C and held for 2 minutes. All data were recorded and processed using Chemstation software.

### Gas Chromatograph-Mass Spectrometry

Gas Chromatograph-Mass Spectrometry (GC-MS) analysis was done using USEPA Method 508 (U.S. Environmental Protection Agency, 1995). For this analysis, 0.5 mL of extracted sample was transferred into a GC auto-sampler vial, then 25  $\mu$ L of  $d_{10}$ -phenanthrene (10 mg/L in isooctane) internal standard was added to the vial to make a final concentration of 500  $\mu$ g/L. An Agilent 6890 gas chromatograph with a 5973N mass spectral detector equipped with a liquid auto-sampler was used for this analysis. Mass separation was done using a Hewlett-Packard-5 ms column (30 m x 250  $\mu$ m, 0.25- $\mu$ m film thickness); two  $\mu$ L sample was injected into the instrument using splitless mode. The carrier gas used was high purity helium at a constant flow rate of 1 mL/min. The sample inlet, mass spectral quad detector, and source temperature was 280 °C, 150 °C, and 230 °C, respectively. The oven temperature was programmed as: Initial temperature 100 °C, then ramped at 40 °C/min to 170 °C followed by 3 °C/min to 185 °C, then at 10 °C/min to 220 °C, and finally 60 °C/min to 280 °C and held for 6.75 minutes. The total run time was 18 minutes. Selected ion monitoring mode was used for quantification of the pesticides atrazine, simazine, heptachlor, methoxychlor, and prometon. The quantification ions and the qualifier ions for each pesticide detection are

listed in table 1. All data were recorded and processed using Hewlett-Packard Chemstation software.

**Table 1.** Quantification ion and qualifier ion data for the Gas Chromatograph-Mass Spectrometry methods used for environmental samples.

[MW, molecular weight; --, no data]

Pesticide	MW	Quantification	Qualifier	Qualifier
		ion mass	ion 1	ion 2
Atrazine	216	200	215	173
Simazine	202	201	186	173
Heptachlor	373	272	237	--
Methoxychlor	346	227	152	169
Prometon	225	210	225	183
Phenanthrene- $d_{10}$ (Internal Standard)	188	188	160	--

## Chemical Data Quality Assurance

This section will provide the user of these data with the assurance that they meet defined standards of quality with a stated level of confidence (U.S. Environmental Protection Agency, 1998, 2002a; Taylor, 1987). Because these analyses were done by a research laboratory and not a production laboratory where rigorous quality assurance plans exist, it is necessary to publish the laboratory quality assurance procedures and results for this study.

### Total Organic Carbon and Inorganic Carbon Data Quality

The quality assurance procedures used for TOC analysis are consistent with those present in the analysis method (U.S. Environmental Protection Agency, 2002b) and the instrument's operation manual. The Sklar Primacs carbon analyzer was calibrated before analysis using increasing weights of calcium carbonate (10 to 100 mg) to establish a calibration curve. A duplicate sample was run with each group of 10 unknowns to establish analytical precision. Results of these duplicates indicate that the precision of analysis is excellent for the TOC and inorganic carbon results. Calibration checks and standard soil check samples were run before and after each group of 10 unknowns. Five reference standard samples ranging from 0.46 to 12.0 percent carbon were measured as part of the analytical precision checks. All 31 analyses of these five standards were within acceptable limits of +/- 20 percent.

### Trace Element and Iron Data Quality

U.S. Environmental Protection Agency Methods 3051A and 200.8 in this study were used to analyze 157 samples. The

following sections describe the instrument calibration, method detection limits, control samples, and other validations for these environmental data.

## Instrument Calibration

For all of the detection methods and instruments used in this study, the instrument responses were calibrated with standard solutions using a range of concentrations. The estimated instrument detection limits were calculated at 3 to 5 times of signal/noise ratio. The linear ranges of the calibration were determined and used for the quantitative analysis of the samples.

Initial calibration was performed with the element concentrations of 0.02, 0.1, 1, 10, 100, 500, and 1,000 µg/L. All element calibration curves were linear up to 1 mg/L with ICP-MS detection methods. This linearity was consistent with the observed range of concentrations in the environmental samples.

## Method Detection Limit

The Method Detection Limit (MDL) is based on the ability of a method to determine an analyte in a sample matrix regardless of its source of origin (Taylor, 1987). The quantitative MDL for this study was determined by fortifying reagent blanks with 2 to 5 times the concentration of the estimated instrument detection limit. This represents the lower limit of analyte detection with 99 percent confidence (table 2). Seven replicates were analyzed and results were used to calculate the MDL using the equation:

$$\text{MDL} = \text{SD} \times t \quad (2)$$

where:

- SD is the standard deviation of the replicated analysis, and  
t is the student's t value for a 99 percent confidence level and a standard deviation estimate with n-1 degrees of freedom (t = 3.14 for 7 replicates).

**Table 2.** Method detection limit for each element.

[MDL, method detection limit; mg/kg, milligram/kilogram]

Element	MDL in dry soil (mg/kg)	
	Single extraction	Sequential extraction
Vanadium	0.14	1.00
Chromium	0.59	1.00
Copper	0.36	0.40
Cadmium	0.06	0.01
Lead	0.07	0.10
Arsenic	0.12	0.10
Mercury	0.02	None
Iron	15.0	15.0

## Laboratory Reagent Blank

The purpose of a Laboratory Reagent Blank (LRB) is to define error from sources external to the environmental sample. These sources of error or contamination potentially can be introduced from the laboratory environment, the reagents used in the analysis, the analytical instruments, and the analyst. At least one LRB was prepared and measured for each batch run of up to 20 samples. Laboratory Reagent Blanks were prepared and measured using the same procedure as for the environmental samples. The nine LRBs and results for each trace element measured by USEPA Methods 3051A and 200.8 are listed in table 3. Theoretically, these LRBs should have no detectable concentrations of elements. Vanadium was detected eight times above the MDL of 0.14 milligram per kilogram (mg/kg), but more than one order of magnitude lower than the typical environmental sample concentration. In some LRBs, mercury had detectable concentrations above the MDL. Generally, results indicated that contamination is not being introduced into the samples from external sources that would appreciably compromise the results of the environmental samples. No correction for blank concentrations was employed in the final environmental sample results.

**Table 3.** Results of laboratory reagent blank samples.

[All concentrations in units of milligrams per kilogram; LRB, laboratory reagent blank; ND, no detection]

LRB	Vanadium	Chromium	Copper	Cadmium	Lead	Arsenic	Mercury
1	0.23	ND	ND	ND	ND	ND	ND
2	0.33	ND	ND	ND	ND	ND	ND
3	1.05	ND	ND	ND	ND	ND	ND
4	0.83	ND	ND	ND	ND	ND	ND
5	ND	ND	ND	ND	ND	ND	ND
6	0.68	ND	ND	ND	ND	ND	0.02
7	0.52	ND	ND	ND	ND	ND	0.03
8	0.41	ND	ND	ND	ND	ND	0.02
Replicate	0.44	ND	ND	ND	ND	ND	0.03

## Reference Standard Samples

Reference standards are used to test the recovery of analytes by the analytical instrumentation. For the ICP-MS analysis, two standards were used to check the method performance. Reference standard 1 was certified drinking water (Cat # CRM-RMDW-A), and reference standard 2 was certified wastewater (Cat# CWW-TM-C). The method validation and quality assurance were performed by spiking these standards into the environmental samples before digestion, followed by analysis using USEPA Method 200.8 for each batch run (U.S. Environmental Protection Agency, 1994). Although certified soil samples would have been the better reference standard to use, using certified water reference standards is an acceptable substitute for this method performance validation and allowed us to consider matrix interference in the recovery results. Results of reference standard recoveries are presented in table 4.



**Table 4.** Results of drinking water and waste water reference standard sample recovery.

[µg/L, microgram per liter; mg/L, milligram per liter]

Element	Certified concentration	Reference standard 1 (µg/L)		Certified concentration	Reference standard 2 (mg/L)	
		Detected concentration	Percent recovery		Detected concentration	Percent recovery
Vanadium	35.0	41.6	119	50.0	47.1	94.3
Chromium	20.0	20.6	103	50.0	47.0	93.9
Copper	20.0	21.7	108	50.0	54.6	109
Cadmium	10.0	11.2	112	15.0	15.9	106
Lead	20.0	20.1	101	50.0	48.0	96.0
Arsenic	55.0	57.5	105	15.0	16.0	107

## Laboratory Fortified Samples

Laboratory fortified samples (LFS), also called sample spikes, are used to test or validate the recovery of analytes from spiked samples. When the appropriate sample reference is absent, the LFS is done to validate the method performance and to confirm that the sample matrix is not interfering with analyte detection. A LFS was performed with each batch run of up to 20 samples. A known amount of the standard was added to the sample and mixed well, and the extraction and analysis were performed using the same procedures as for the environmental samples. The percent recovery of the LFS was calculated by the equation listed below; and the results are presented in table 5. Generally, recovery of the known analyte quantity was good for all elements except cadmium. It is not known why cadmium recovery was a problem, but seems to be related to the sample matrix because the fortified blank recoveries were excellent for all trace elements (table 5).

$$\% \text{ Recovery} = 100 \times (C_{fs} - C_s) / C_{add} \quad (3)$$

where:

$C_{fs}$  is the detected fortified sample concentration,  
 $C_s$  is the detected sample concentration, and  
 $C_{add}$  is the concentration of standard added.

**Table 5.** Results of laboratory fortified samples.

[All results represent percent recovery; LFS, laboratory fortified sample; SPK, spike; --, no data]

LFS-SPK	Vanadium	Chromium	Copper	Cadmium	Lead	Arsenic	Mercury
8	--	--	--	--	--	--	99.3
19	105	101	86.5	69.1	105	112	92.8
29	82.3	94.9	85.3	83	77.7	94.8	102
46	120	93.6	80.6	82	93.3	84.2	119
99	87.5	93.1	81.9	84.9	126	111	100
116	114	103	103	93.2	103	108	89.4
121	109	103	97.6	66.7	97.9	100	97.3

## Laboratory Fortified Blanks

Laboratory Fortified Blanks (LFB) were used to test the recovery of each trace analyte in the absence of matrix interference. Three LFBs were analyzed using the same methods for the environmental samples. Each blank was spiked with a known amount of the standard and analyzed. The percent recovery was calculated using the formula below, and the results are given in table 6. Overall, the percent recovery for all of the elements was within 80 to 120 percent. The lower mercury recovery may be because of the volatile nature of this trace element and possible loss during analysis.

$$\% \text{ Recovery} = 100 \times \text{Concentration detected} / \text{Concentration added} \quad (4)$$

**Table 6.** Results of laboratory fortified blanks.

[All results represent percent recovery; LFB, laboratory fortified blank; SPK, spike]

LFB-SPK	Vanadium	Chromium	Copper	Cadmium	Lead	Arsenic	Mercury
1	115	118	118	117	121	121	97.8
2	115	107	113	108	111	109	82.3
3	102	94.1	101	101	101	97.8	90.9

## Calibration Check

To monitor the instrument performance, standard solutions were measured during batch runs. At least one standard solution was measured for every 10 to 15 samples to ensure the instrument is calibrated and working properly; calibration checks during sample analysis are shown in table 7.

## Precision of Duplicated Samples

One or more duplicate samples were analyzed for each batch of up to 20 samples. Duplicates were measured for single and sequential extraction methods (tables 8 and 9).

The precision of the duplication is expressed as the relative percent difference (RPD) and is calculated using the equation below. Based on USEPA guidance for sampling and analysis of sediments, the quality control criterion for analysis precision should be no greater than 30 to 50 percent RPD (U.S. Environmental Protection Agency, 2002a). Considering this criterion, the precision of analysis for post-hurricane samples is excellent.

$$RPD = 100 \times (C_h - C_l) / C_{av} \quad (5)$$

where

- $C_h$  is detected high concentration of duplicated sample,  
 $C_l$  is detected low concentration of duplicated sample, and  
 $C_{av}$  is the average of the  $C_h$  and  $C_l$

**Table 7.** Results of calibration checks.

[All results represent percent recovery]

Calibration check	Vanadium	Chromium	Copper	Cadmium	Lead	Arsenic	Mercury
1	97.8	97.2	97.3	93.5	95.8	92.9	95.5
2	96.1	96.1	96.5	90.5	94.6	95.2	98.6
3	96.2	95.8	98.1	88.3	95.6	96.8	104
4	96.3	96.8	96.9	94.3	96	95.8	101
5	91	90.5	89	92	91	117	101
6	98.9	99.5	99.9	97.2	99.5	104	103
7	96.2	101	111	95.3	99.9	98.8	91
8	107	96.1	104	103	106	102	92.1
9	106	105	103	107	105	122	95.6

**Table 8.** Results of single extraction duplicate samples used to measure the precision of analysis.

[All results represent percent difference; D, duplicate; --, no data]

Sample number pairs	Vanadium	Chromium	Copper	Cadmium	Lead	Arsenic	Mercury	Iron
8/8-D	12.8	12.3	0.80	3.80	5.20	12	8.60	10.9
19/19-D	2.80	6.60	4.20	10.0	5.00	9.10	4.20	4.40
29/29-D	14.7	12.1	4.40	1.30	5.30	9.10	--	5.50
46/46-D	3.10	8.20	5.40	16.8	0.60	57.2	0.00	17.6
66/66-D	3.60	4.80	2.30	1.30	1.40	6.60	4.40	1.90
99/99-D	7.40	0.70	4.50	9.00	0.90	8.30	8.00	5.60
116/116-D	12.4	2.90	12.6	35.9	4.10	16.1	19.2	4.90
121/121-D	2.70	5.30	50.8	8.40	6.90	9.10	10.7	4.00

## Pesticide and Polychlorinated Biphenyl Data Quality

### Gas Chromatograph-Electron Capture Detection

The pesticides and the arochlors were detected simultaneously by Gas Chromatograph-Electron Capture Detection (GC-ECD). Upon review of the chromatograms, atrazine, simazine, heptachlor, methoxychlor, surrogate pentachloronitrobenzene, and internal standard 2,4,5,6-tetrachloro-m-xylene were well separated with the two Aroclor standards 1016 and 1260.

### Instrument Calibration

Initial calibration was performed with seven points standards at the concentration ranges of 0.05 ppm to 10 ppm of atrazine, simazine, Aroclor 1016 and 1260; 1.00 parts per billion (ppb) to 2 ppb heptachlor, 2.00 ppb to 400 ppb methoxychlor. The linear ranges of atrazine, simazine, and the Arochlors were up to 3 ppm whereas heptachlor and methoxychlor calibration curve were linear for all of seven concentrations used for calibration. The correlation coefficient for each pesticide and the two Aroclor endmember congeners was 0.99, indicating that excellent instrument calibration was achieved.

### Method Detection Limit

The MDL were determined by fortifying low concentration standards into the reagent blank. The same method of calculating MDLs for the trace elements was used for pesticides and the polychlorinated biphenyl Aroclor congeners. The MDLs for pesticides and Aroclor congeners are listed in table 10.

### Laboratory Fortified Blank

Laboratory Fortified Blanks (LFB) were used to test the recovery of each compound in the absence of matrix interference; results are shown in table 11. Recovery of spiked pesticide compound concentrations was good for all pesticides with the exception of simazine. Aroclor congener 1016, 1260 and surrogate penta chloronitrobenzene (PCHB) had acceptable recoveries. Recovery for surrogate compounds are considered acceptable when they range between 70 to 130 percent (U.S. Environmental Protection Agency, 1995).

### Laboratory Fortified Sample

Laboratory Fortified Samples (LFS) are used to test the effects of the sample matrix on the recovery of spiked sample media. Results indicate that the recovery of spiked concentrations of pesticides and PCB Arochlors generally were good (table 12). Two samples could not be quantified because the background concentration was too large.

**Table 9.** Results of sequential extraction duplicate samples used to measure the precision of analysis.

[mg/kg, milligram per kilogram; F1, exchangeable fraction; <, less than; F2, bound to carbonate fraction; F3, iron and manganese oxides fraction; F4, organic matter fraction; F5, residual; D, duplicate]

Element	Fraction	Concentration (mg/kg)										Relative percent difference of duplicated samples				
		30	30-D	31	31-D	66	66-D	153	153-D	31/31-D	30/30-D	66/66-D	153/153-D			
Vanadium	F1	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	0.00	0.00	0.00	0.00
	F2	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	0.00	0.00	0.00	0.00
	F3	3.94	3.76	8.78	9.65	7.16	7.50	17.0	16.7	9.44	4.68	4.64	1.96			
	F4	2.21	1.84	1.21	2.96	2.66	4.61	6.05	5.74	83.9	18.3	53.6	5.26			
	F5	12.2	15.1	50.8	68.1	26.7	13.9	63.7	63.4	29.1	21.4	63.3	0.46			
Total F	18.4	20.7	61.4	78.0	36.5	26.0	86.8	85.8	23.9	12.1	33.8	1.09				
Chromium	F1	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	0.00	0.00	0.00	0.00
	F2	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	0.00	0.00	0.00	0.00
	F3	0.95	1.05	3.96	4.33	1.93	2.08	2.97	2.82	8.93	10.0	7.48	5.18			
	F4	2.51	1.76	7.57	9.07	4.75	5.50	4.25	3.16	18.0	35.1	14.6	29.4			
	F5	7.49	8.72	32.2	28.6	13.3	8.55	32.7	32.9	11.8	15.2	43.8	0.43			
Total F	10.9	11.5	43.7	42.0	20.0	16.1	40.0	38.9	4.01	5.16	21.5	2.79				
Copper	F1	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	<0.40	0.00	0.00	0.00	0.00
	F2	<0.40	<0.40	1.66	1.65	<0.40	<0.40	0.55	0.49	0.60	0.00	0.00	11.5			
	F3	1.00	0.80	3.03	3.24	0.55	0.5	1.71	1.87	6.7	22.2	9.52	8.94			
	F4	1.02	1.03	26.6	26.1	1.19	1.31	3.19	2.01	1.78	0.98	9.60	45.4			
	F5	6.48	6.89	26.3	25.4	7.83	8.97	20.7	19.3	3.49	6.13	13.6	7.11			
Total F	8.50	8.72	57.6	56.4	9.57	10.8	26.1	23.6	2.07	2.56	11.9	10.00				
Cadmium	F1	0.25	0.26	0.67	0.72	0.21	0.23	<0.01	<0.01	7.34	3.21	7.92	0.00			
	F2	<0.01	<0.01	0.60	0.59	<0.01	<0.01	0.15	<0.01	0.95	0.00	0.00	0.00			
	F3	0.07	0.05	1.30	1.29	0.08	0.08	0.21	0.11	0.36	21.5	1.15	57.4			
	F4	<0.01	<0.01	0.11	0.10	0.01	0.01	0.03	0.02	16.1	0.00	38.3	16.1			
	F5	<0.01	<0.01	0.04	0.03	<0.01	<0.01	0.05	0.22	17.9	0.00	0.00	129			
Total F	0.32	0.31	2.72	2.73	0.03	0.32	0.43	0.35	0.37	3.17	6.45	20.5				



**Table 9.** Results of sequential extraction duplicate samples used to measure the precision of analysis.—Continued

[mg/kg, milligram per kilogram; F1, exchangeable fraction; <, less than; F2, bound to carbonate fraction; F3, iron and manganese oxides fraction; F4, organic matter fraction; F5, residual; D, duplicate]

Element	Fraction	Concentration (mg/kg)										Relative percent difference of duplicated samples				
		30	30-D	31	31-D	66	66-D	153	153-D	31/31-D	30/30-D	66/66-D	153/153-D			
Lead	F1	5.08	4.66	0.21	0.19	0.18	0.32	<0.10	<0.10	11.0	8.67	57.8	0.00			
	F2	4.2	4.29	14.6	14.8	0.56	0.55	2.27	1.83	1.01	2.19	2.50	21.4			
	F3	15.6	13.8	41.8	44.86	7.00	6.43	10.1	10.0	7.18	11.9	8.45	0.03			
	F4	5.03	4.81	17.2	22.3	5.00	5.20	2.90	1.51	25.6	4.41	4.00	62.7			
	F5	7.93	8.07	36.4	26.5	7.10	8.85	13.5	11.4	31.5	1.78	21.9	16.6			
	Total F	37.8	35.7	110	108	19.8	21.3	28.7	24.8	1.48	5.83	7.34	14.53			
Arsenic	F1	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.00	0.00	0.00	0.00			
	F2	1.06	1.00	0.49	0.52	<0.10	<0.10	0.17	0.11	5.41	5.53	0.00	41.2			
	F3	28.3	27.9	14.5	15.2	6.93	6.54	3.49	2.45	4.85	1.42	5.65	34.8			
	F4	3.9	3.33	0.79	1.25	0.41	0.48	<0.10	<0.10	44.42	15.6	16.5	0.00			
	F5	5.84	5.39	11.9	9.80	3.54	4.38	4.73	4.59	19.29	8.03	21.1	2.90			
	Total F	39.1	37.6	27.7	26.8	10.9	11.4	8.38	7.16	3.30	3.83	4.67	15.7			
Iron	F1	<15.0	<15.0	<15.0	<15.0	<15.0	<15.0	<15.0	<15.0	0.00	0.00	0.00	0.00			
	F2	127	139	106	117	<15.0	<15.0	68.0	54.0	9.90	9.18	0.00	23.5			
	F3	2,520	2,950	5,590	7,610	4,000	4,430	4,750	3,430	30.71	15.7	10.1	32.2			
	F4	462	422	4,340	4,710	1,220	1,460	615	338	8.26	8.86	17.5	58.3			
	F5	4,130	4,910	19,100	23,000	12,200	9,190	18,900	17,800	18.16	17.2	28.1	6.26			
	Total F	7,240	8,420	29,100	35,400	17,400	15,100	24,400	21,600	19.31	15.1	14.4	12.0			



**Table 10.** Method detection limit of pesticides and arochlor by Gas Chromatograph-Electron Capture Detection.[MDL, method detection limit;  $\mu\text{g}/\text{kg}$ , microgram per kilogram]

Compound	MDL ( $\mu\text{g}/\text{kg}$ dry soil)
Simazine	11.8
Atrazine	9.40
Heptachlor	0.40
Methoxychlor	0.40
Arochlor 1016	7.90
Arochlor 1221	7.90
Arochlor 1232	7.90
Arochlor 1242	7.90
Arochlor 1248	7.90
Arochlor 1254	7.90
Arochlor 1260	3.60

**Table 11.** Results of laboratory fortified blanks for pesticides, Arochlor, and surrogate compounds.

[All results represent percent recovery; LFB, lab fortified blank; RSPK, reagent spike; PCNB, penta chloronitrobenzene; --, no data]

LFB-RSPK	Simazine	Atrazine	Heptachlor	Methoxychlor	Arochlor 1016	Arochlor 1260	Surrogate PCNB
1	87.2	108	118	104	--	--	--
2	83.8	96.3	118	109	86.4	99	80.4
3	79.9	85.2	111	97.1	104	98.9	91.0
4	84.8	106	85.0	--	92.2	99.1	91.4

## Gas Chromatograph-Mass Spectrometry Method

### Instrument Calibration

Some samples were analyzed by Gas Chromatograph-Mass Spectrometry Method (GC-MS). For example, samples with high background concentrations precluded the use of GC-ECD detection. GC-MS also was used to confirm pesticides concentrations detected by the GC-ECD analysis.

**Table 12.** Results of laboratory fortified sample recovery for pesticides, arochlor, and surrogate compounds.

[All results represent percent recovery; LFS, lab fortified sample; SPK, spike; PCNB, penta chloronitrobenzene; --, no data]

LFS-SPK	Simazine	Atrazine	Heptachlor	Methoxychlor	Arochlor 1016	Arochlor 1260	Surrogate PCNB
12	94.7	98.1	115.2	--	95.2	97.0	86.7
20	110	116	100	--	94.7	95.3	87.5
46	93.8	90.3	87.6	97	92.2	101	--
85	101	101	79.3	--	94.2	99.6	100
125	--	78.8	121	84.5	85.7	103	87.1
137	87.4	88.9	122	112	97.0	103	82.9

A 10-points initial calibration was performed for the pesticides prometon, simazine, atrazine, heptachlor, and methoxychlor at concentrations ranging from 2.00 to 1,000  $\mu\text{g}/\text{L}$ . All of the pesticides calibrations were linear within these calibration ranges. Methoxychlor calibration was specifically linear within the concentration range of 10.0  $\mu\text{g}/\text{L}$  to 1,000  $\mu\text{g}/\text{L}$ . A correlation coefficient of calibration better than 0.99 was determined for all pesticide compounds measured.

### Method Detection Limit

The MDLs were determined by fortifying low concentration standards into seven replicates of reagent blank. The MDLs of the pesticides calculated for prometon, simazine, atrazine heptachlor, and methoxychlor are 0.67, 0.44, 0.27, 0.44, and 3.47 microgram per kilogram ( $\mu\text{g}/\text{kg}$ ), respectively.

## Environmental Chemical Data

The chemical constituents selected for this analysis were thought to be the constituents most likely to be bonded with sediments following the mixing of sediment and water with the diverse hurricane debris consisting of automobiles, boats, household wastes, building materials, industrial equipment, and assorted chemicals. This reporting is limited to the presentation of the distribution of data within the dataset. No analysis has been conducted to relate the concentrations data with the areas where the samples were collected, however, with respect to organic carbon results, a description of the general locations of the sample results is given to facilitate the understanding of the likelihood of their occurrence. It is solely up to the reader to make that assessment based on the sampling locations presented in figure 5 and the concentration data contained in table13, at the back of this report.

### Total Organic Carbon Results

The 2005 storm season transported massive amounts of organic carbon to New Orleans and the Delta by inundating the surrounding areas with floodwaters and debris. The source

of most of the carbon came from the upper layer of soils within the marshes, swamps, surface/subsurface hydrologic features surrounding the area, and transported anthropogenic debris.

This study indicated that the TOC generally is larger in the northern sample points of the study area. One of the dominating trace element adsorbing surfaces in this part of the study area is the organic matter. Since most of the northern section of the study area is made up of silt, clay, peat, and organic matter, trace elements are adsorbed easily. Osgood and Ziemann (1993) and Osgood and others (1995) determined that sandy marsh sediments associated with marshes in Virginia had lower organic content than siltier sites nearby. Additionally, as the silt-clay content (percent of dry weight) of a soil increases so does the TOC (percent of dry weight) (National Oceanic and Atmospheric Administration, 2004). This helps to explain why the TOC values in the northern section of the study area are larger than the values in the southern areas where the soil becomes sandier and grain size becomes coarser.

There were 150 samples processed for percent TOC; seven samples did not have enough sediment remaining to be processed (table 13). Values ranged from 0.01 to 17.9 percent in dry soil. A regression analysis was conducted between TOC and V, Cr, Cu, Cd, Pb, As, Hg, and Fe; however, no correlation was observed. Graphical results of the regression analysis are not presented in this report

## Trace Element and Iron Single Extraction Results

The sample results for total digested trace element analysis for V, Cd, Cr, Cu, Pb, As, and Hg, along with summary statistics, are listed in table 13, and the distribution

of these results, sorted by element, are shown in figure 7. The largest range in constituent concentration variability in decreasing order, was observed for Pb, V, Cr, Cu, As, Cd, and Hg. A single sample had a copper concentration of 960 mg/kg, and represented the largest concentration of all the analyzed trace elements. Also, this concentration represented a significant outlier in the copper dataset and did not relate to the other trace element concentrations determined for the same sample.

Generally, lead concentration was observed to be consistently larger than the detection level for all samples, and ranged from 4.50 to 551 mg/kg. The large range and large overall concentrations for lead in sediments is consistent with pre-hurricane lead studies of residential soils in New Orleans (Mielke and others, 2007, 2000, 1997, 1999, and 2006). This finding suggests that debris from the hurricane may not have increased lead concentration, but the hurricane itself was responsible for redistributing already contaminated sediments and soils throughout New Orleans and the Delta. It should be noted that the USEPA has established a 400 ppm by weight lead standard for bare residential soils in child playground areas and an average concentration of 1,200 ppm in non-playground areas (U.S. Environmental Protection Agency, 2006a). Results of this analysis identified only two samples with concentrations exceeding the lower standard; nevertheless, the USEPA standard suggests that a lead hazard may occur from the creation of dust during the sediment removal process in New Orleans. Sediment removal is not a concern in the Delta region where the landscape primarily is rural and storm-related sediment deposition was minimal.

Vanadium concentrations in samples represented the most normal distribution of all constituents measured, ranging from 5.7 to 92.1 mg/kg. There were no extreme outlier concentrations of vanadium for any sample, which is consistent with

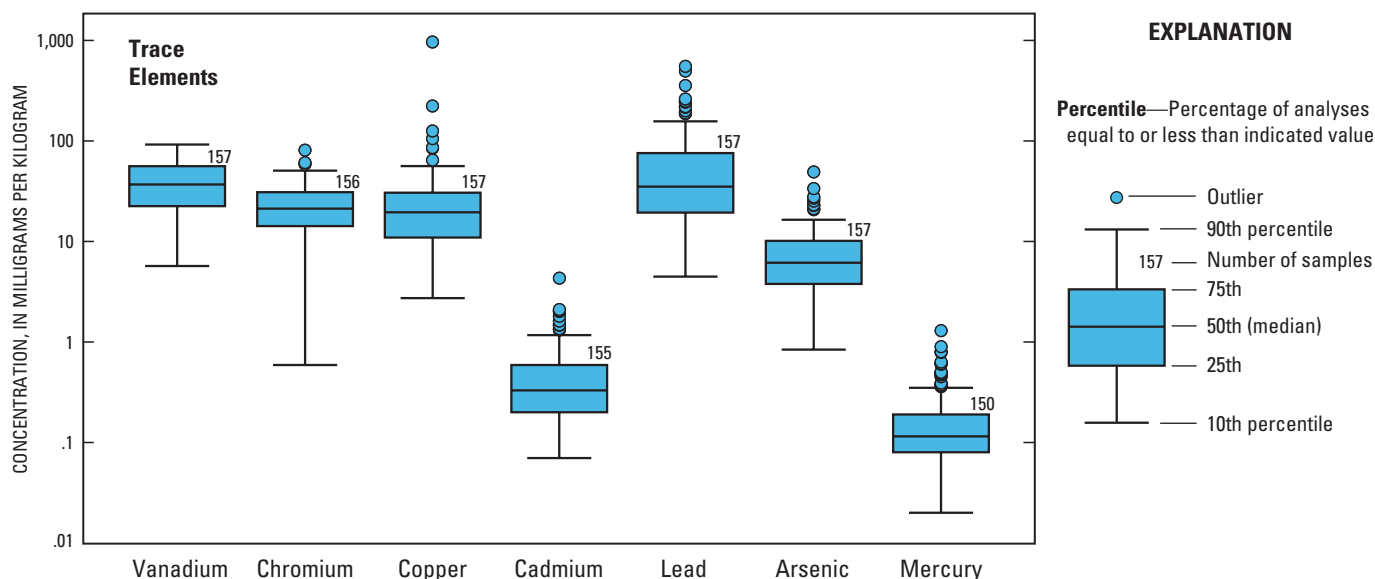


Figure 7. Boxplots showing the distribution and range of trace element data analyzed using the single extraction method.

pre-hurricane studies of fresh Mississippi River delta alluvium and New Orleans alluvial soils (Mielke and others, 2000). Vanadium is associated with automotive waste, machinery, and some industrial processes linked to the southern Louisiana region. Overall, the concentration levels observed from these samples do not indicate a substantial hurricane affected contamination problem.

Chromium and copper tend to have similar variable relations with the exception of the number of outliers (fig. 7). Chromium ranged from 0.59 to 81.1 mg/kg and its data distribution only possessed two extreme outliers (fig. 7), but are within the range of concentrations (non-detect to 205 mg/kg for urban New Orleans; 0.30 to 3.00 for fresh Mississippi alluvium) of pre-hurricane samples collected and analyzed by Mielke and others (2000). Chromium has been determined to be a dominant trace element in New Orleans soils and is associated with lead and copper (Mielke and others, 2000). The relation among the post-hurricane samples of this study does not appear to be that clear.

The use of arsenic in household chemicals, industrial processes, and agricultural chemicals is becoming more limited; however, historical use of this trace element in treated wood products and some pesticides was expected to resurface in sediment scoured from Lake Pontchartrain, the urban soil environment, and the industrial canals. The variability of arsenic between sample sites is small, and the median concentration is substantially below the median concentrations for vanadium, lead, chromium, and copper (table 13, fig. 7). Furthermore, arsenic concentration in samples is relatively small, ranging from 0.84 to 49.1 mg/kg. These results compare well to a study by Cobb and others (2006), where concentrations in 43 samples collected in three longitudinal transects within the center of New Orleans following Hurricanes Katrina and Rita ranged from 0.23 to 28.0 mg/kg. The USEPA Region 6 has established two screening levels for arsenic detected in soil; a cancer Human Health Medium-Specific Screening Level (HHMSSL) of 0.39 mg/kg and a non-cancer HHMSSL of 22 mg/kg. These screening levels are chemical concentrations that correspond to fixed levels of risk in soils, air, and water. The cancer HHMSSL represents a one in one million [ $10^{-6}$ ] chance of contracting cancer at the established technical concentration; the non-cancer HHMSSL represents the concentration level at which other health risks may occur that are not related to cancer (U.S. Environmental Protection Agency, 2006a). U.S. Environmental Protection Agency notes that these are not considered regulatory 'action' or 'cleanup' levels, but can be used as a technical tool in evaluating potential risk to human health. All samples in this study had arsenic concentrations above the cancer HHMSSL and seven samples had concentrations above the non-cancer HHMSSL.

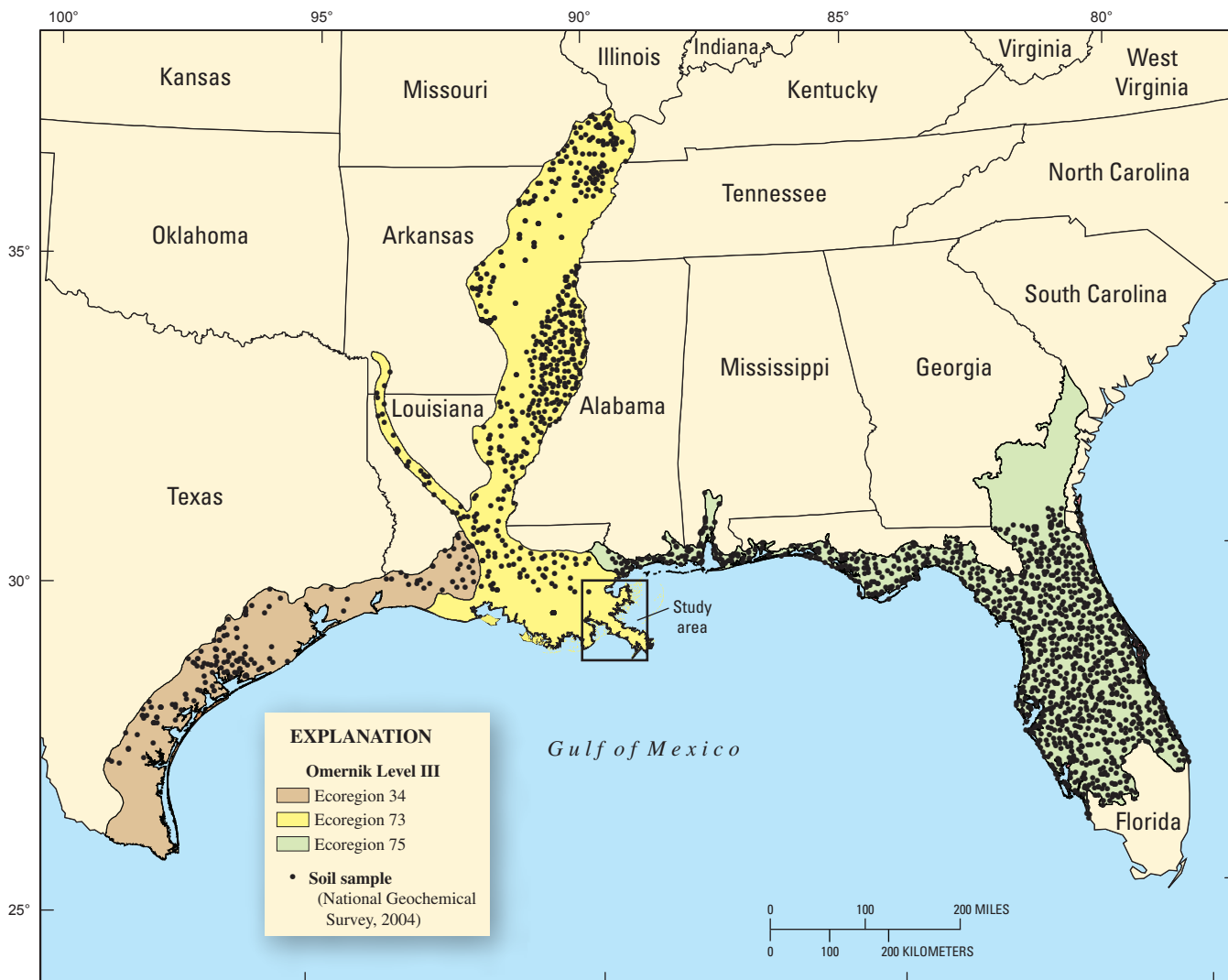
Cadmium concentration in samples ranged from 0.07 to 4.30 mg/kg, with a median concentration of 0.33 mg/kg (table 13, fig. 7). The presence of cadmium in the environment is linked to the deposition of cadmium-laden dust from industrial processes. Hurricanes Katrina and Rita probably

did not increase the concentration levels in New Orleans soil and sediment, but contributed to its distribution throughout the city. An analysis of pre-hurricane Mississippi alluvium and New Orleans soils presents an interesting comparison with these data. Mielke and others (2000) obtained more than 90 samples of Mississippi alluvium and about 4,000 samples of New Orleans soil. The range of their data for the Mississippi alluvium and New Orleans soil was 0.40 to 1.50 mg/kg and non-detection to 87.0 mg/kg, respectively. Mielke's data are consistent with the post-hurricane concentrations present in this study, and indicates that sediments deposited in New Orleans and along the Louisiana Delta are consistent with Mississippi alluvium for the region.

Mercury concentration in samples ranged from 0.02 to 1.30 mg/kg, with a median concentration of 0.11 mg/kg (table 13, fig. 7). Background mercury concentration for soil and sediments in southern Louisiana apparently is nonexistent; however, within the lower Mississippi Valley north of New Orleans and the Delta, mercury concentration in natural soils and sediment averages about 0.04 mg/kg (U.S. Geological Survey, 2004). This was determined from 460 samples collected by the USGS National Geochemical Survey (NGS) in the Level III Omernik Ecoregion 73 (Omernik, 1995). Ecoregion 73 extends from southern Missouri's Mississippi embayment region through southern Louisiana's 'bird foot' Delta (fig. 8). A majority of the samples collected for this study had mercury concentrations exceeding the NGS average concentration. Statistical comparison of the population of post-hurricane data with Ecoregion 73 data indicates that the post-hurricane data are significantly larger than pre-hurricane data for Ecoregion 73. A similar comparison was made for Ecoregions 75 and 34 (fig. 8). These areas bracket the lower Mississippi Alluvial Plain and represent the Gulf of Mexico coastal environment along Texas to the west and Florida to the east of Louisiana. Statistical comparison of these NGS data with post hurricane data indicates that the population of post hurricane data is significantly larger than NGS data in Ecoregions 75 and 34.

Mercury has known health risks when present in its methylated form. The elemental form is not widely present in the environment, and rarely is considered toxic until it makes the transition to methyl mercury. The USEPA Region 6 has a HHMSSL for total mercury of 23.0 mg/kg dry; all of the samples have mercury levels below this screening level.

Elemental iron concentrations were determined to enable geochemical research comparisons for future studies. Because iron analysis was an afterthought in this study, one sample lacked adequate material for analysis. Iron concentrations in samples ranged from 1,530 to 56,200 mg/kg, with a median and mean concentration of 13,700 and 15,100 mg/kg, respectively (table 13). Elemental iron is quite abundant in soils with a global average of 26,000 mg/kg (Sposito, 1989). The USEPA Region 6 has established a HHMSSL of 55,000 mg/kg for iron (U.S. Environmental Protection



Base from Environmental Systems Research Institute digital data, 1983

**Figure 8.** The Omernik Ecoregions and locations of National Geochemical Survey data.

Agency, 2006). The HHMSSL for iron was exceeded in one sample.

The correlation between the total iron concentration and concentrations of other trace elements was analyzed. The correlation analysis results, shown in figure 9, illustrate that V, Cr, Cu, Cd, and As are strongly correlated to the total iron concentration, whereas lead and mercury are not.

The significance of this analysis relates to the researched role that the oxides of major elements play in soil surface adsorption. For example, iron, aluminum, and manganese oxides are sinks for many trace elements, including cations and oxyanions (Basta and others, 2005). Additionally, iron oxide commonly is used as a sorbent for arsenic removal from drinking water, and also is used to adsorb cations such as lead, copper, zinc, and cobalt.

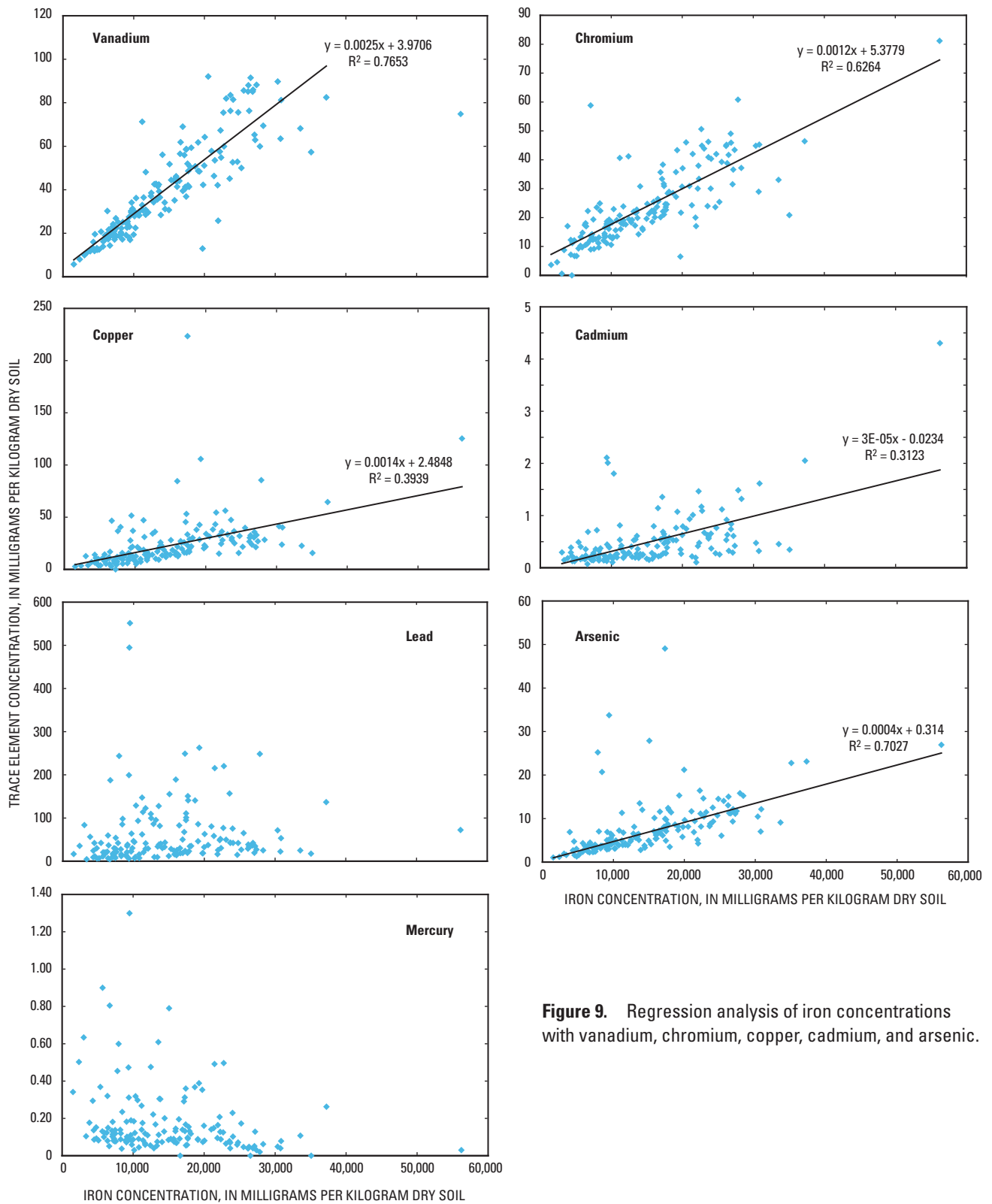
The experiment data in this study are consistent with the previous findings with one exception; lead and mercury results vary because of the impact of other factors such as soil organic

matter, which has a strong binding strength with most heavy metals.

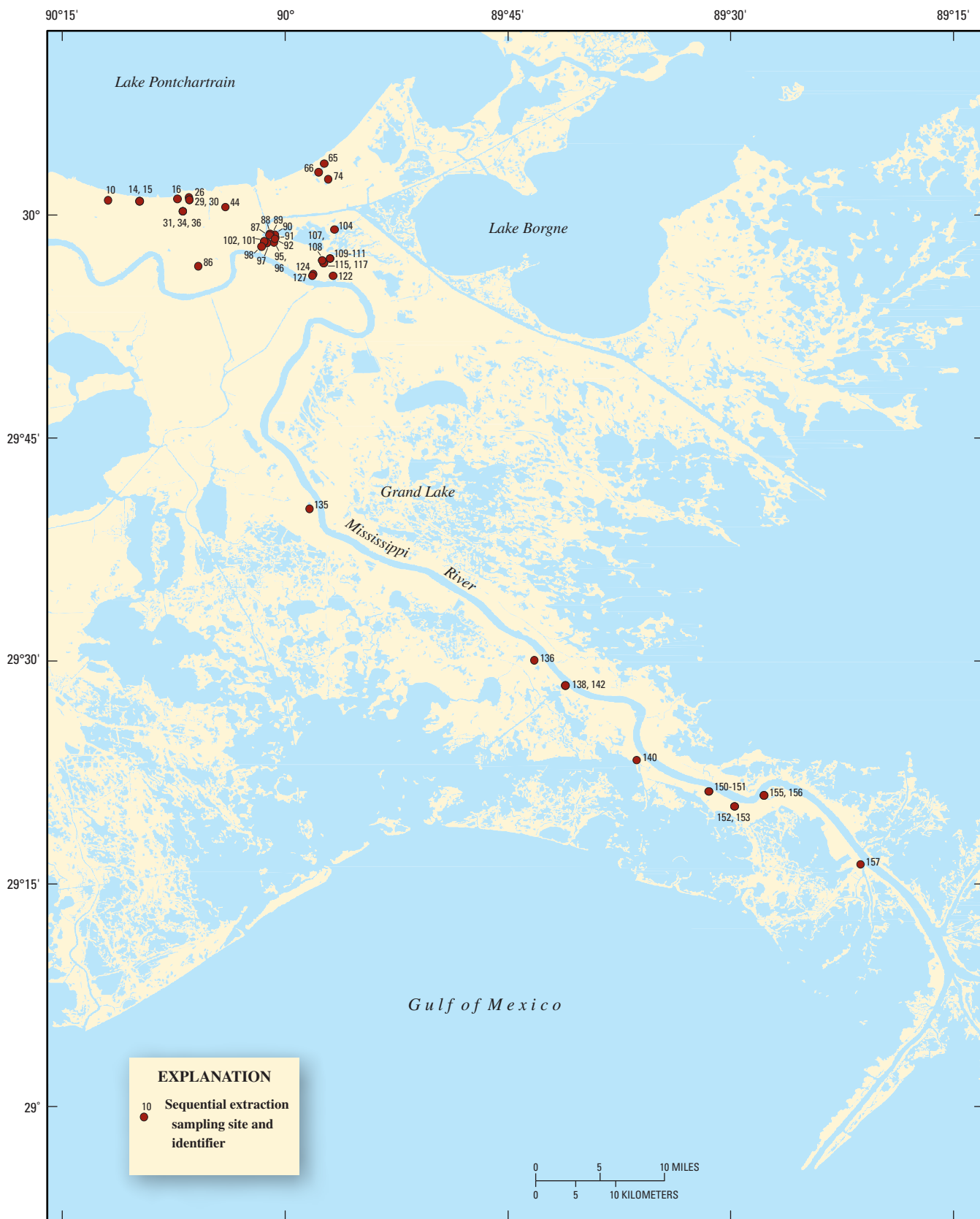
### Trace Element and Iron Sequential Extraction Results

Sequential extraction was completed on 6 of 7 trace elements and iron to determine the binding properties of each element with its host matrix and the partitioning among the various forms in which each element might exist. A subset of 51 samples was selected from the 157 samples that were analyzed by single extraction methods (fig. 10). A comparison of the single extraction data with the sum of the sequentially extracted parts is shown in boxplot format for each element (fig. 11). Sequential extraction is a procedure by which progressively stronger digestion is used to facilitate an understanding of the relative mobility of an element contained in sediments and soils. Therefore, those elements that are



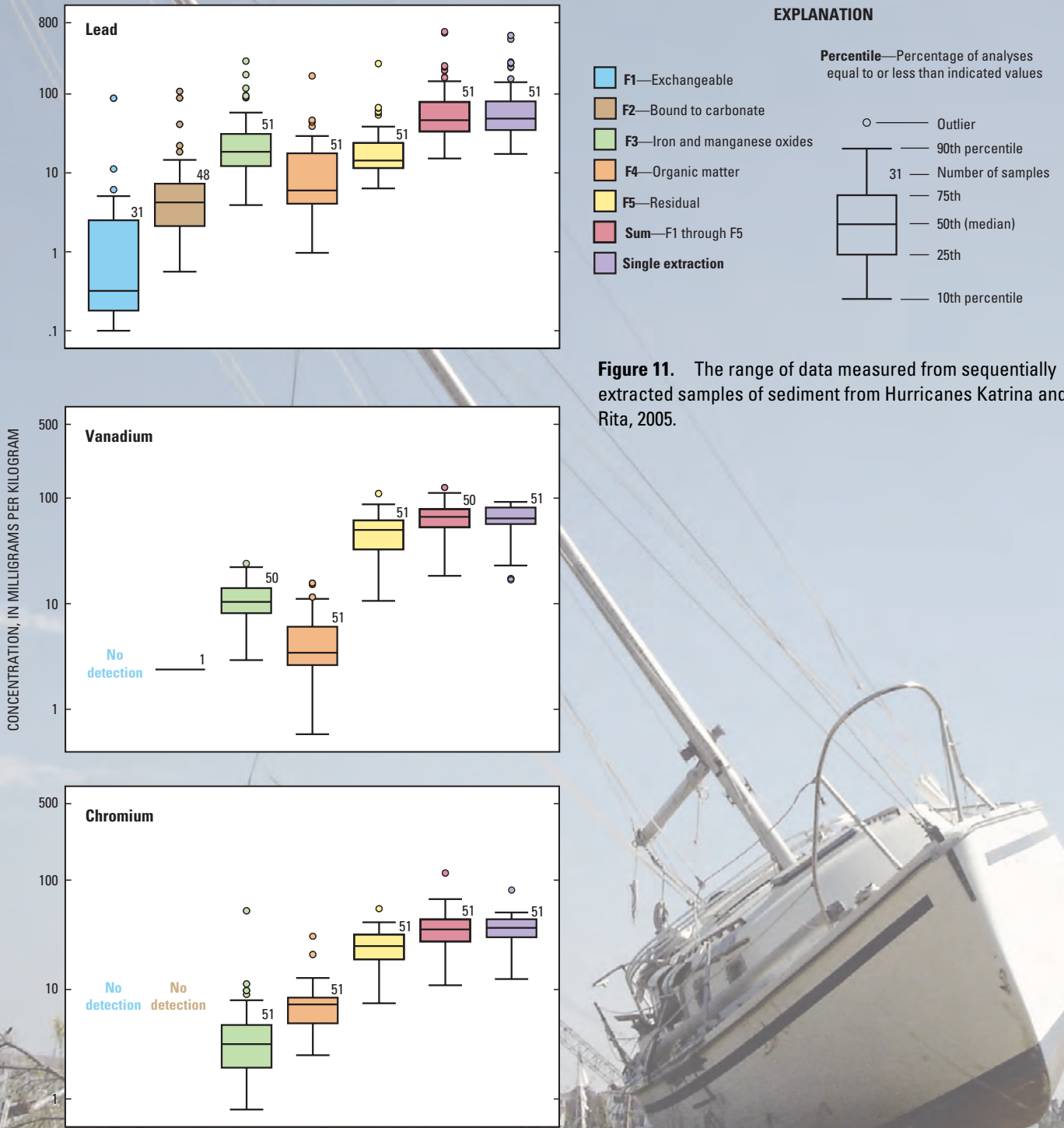


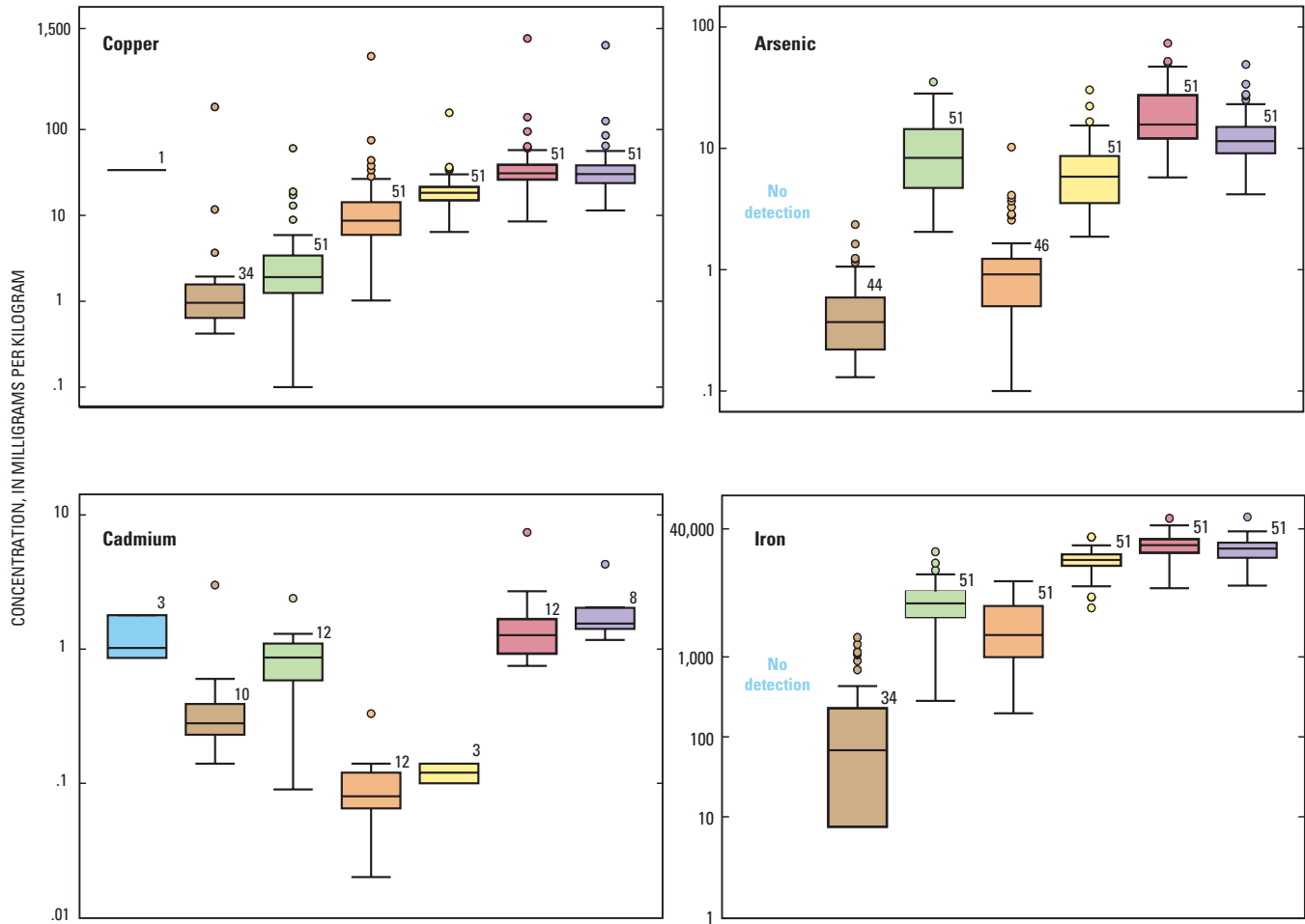
**Figure 9.** Regression analysis of iron concentrations with vanadium, chromium, copper, cadmium, and arsenic.



Base from the Louisiana Oil Spill Coordinator's Office, 2000  
 Horizontal coordinate information referenced to the  
 North American Datum of 1983 (NAD 83)

Figure 10. Locations of samples analyzed using sequential extraction methods.





**Figure 11.** The range of data measured from sequentially extracted samples of sediment from Hurricanes Katrina and Rita, 2005.—Continued

released in the F1 fraction are likely to occur rather rapidly in the environment through small changes in the ionic composition of natural waters. Contrastingly, the elements present in the F5 fractions are more likely to be tightly linked to the crystalline structure of the sediments. These elements are less likely to affect water chemistry or issue other environmental concerns during normal environmental conditions.

Lead concentrations were present in each fraction of the sequential extraction method (table 14, at the back of this report; fig. 11). The F1 fraction concentration ranged from 0.10 to 88.4 mg/kg, and was detected in 31 of 51 samples analyzed. This large concentration range, which accounts for 5 percent of the total mean concentration for the sequential analysis, indicates there is a small mobile phase in the sample that can move from its matrix with changes in pH, association with acid rain, and mixture with estuary and/or seawater. Lead is present in large concentrations in the soils of New Orleans and probably becomes mobile routinely during rainfall events that drain to the canals and Lake Pontchartrain; therefore, the Pb detected in the F1 fraction could be the redistribution of extremely mobile lead that accumulated in the sediments of

Lake Pontchartrain, the city of New Orleans, and the canal for many decades from surface-water drainage. Lead in the F2 fraction, ranging from 0.56 to 108 mg/kg, was present in 48 of 51 samples. This fraction indicates that some lead is tied to carbonates in the sediment and can be easily mobilized with changes in pH. Lead primarily is associated with iron-manganese oxides that are represented by the F3 fraction. All 51 samples had lead in the F3 fraction; the concentration ranged from 3.90 to 260 mg/kg, with an average of 32.7 mg/kg. This fraction represented 39.1 percent of the mean concentration of lead in samples, which is consistent with studies of marine sediments in other regions of the world (Choi and others, 2006). Whereas lead is more stable in the iron-manganese oxides, it can be mobilized with pH changes and more reductive conditions—environments that are likely to be present in canals, Lake Pontchartrain sediments, and land fills. The F4 fraction contained lead concentrations ranging from 0.97 to 169 mg/kg indicating that this element is substantially tied to organics in the sediments. During oxidizing conditions in natural waters, organic matter can be degraded, which can lead to a release of soluble trace elements (Tessier and others,

1979). The residual, or F5 fraction, ranged in lead concentration from 6.36 to 242 mg/kg and represented 30.1 percent of the mean concentration of lead in the sequential analysis. Lead contained within the F5 fraction is not likely to be released into solution under normal environmental conditions because of its association with the crystalline structure of the sediment and soil matrix.

Vanadium was detected in 4 of 5 sequential extraction fractions (table 15, at the back of this report; fig. 11). Vanadium was not detected in the F1 fractions, and only one concentration measuring 2.38 mg/kg was detected in the F2 fraction. In the F3 fraction 50 of 51 samples contained vanadium concentrations ranging from 2.92 to 24.0 mg/kg. Generally, about 17 percent of the vanadium in samples was determined to be associated with the iron-manganese oxides. Even though substantially smaller in overall concentrations, vanadium was detected in all 51 samples of the F4 fraction, indicating that organic matter may be contributing to sequestering this trace element. The concentrations in the F4 fraction ranged from 0.58 to 15.7 mg/kg. These data indicate that about 7.2 percent of the average vanadium concentration detected in all samples is associated with organic matter. The largest concentrations were observed in the F5 fraction where the concentration ranged from 10.6 to 110 mg/kg. These results suggest that 75.2 percent of vanadium in samples is associated with the crystalline non-mobile phase of the sediments. This is not surprising as vanadium can exist in five oxidation states ranging from -1 to +5, and is typically associated with iron. Vanadium toxicity generally is low; however, the toxicity increases as the valence increases (Barceloux, 1999). This element is not particularly significant to this study, but can be an indicator of air pollution as it most commonly is present in industrial dust emissions. It is possible that decades of industry in the southern Louisiana region contributed to a substantial increase in this constituent. Because the pentavalent form ( $V_2O_5$ ) is the most toxic, there is concern that large concentrations of vanadium in dust during sediment removal from New Orleans could cause potential health issues (Sjoberg, 1950).

Sequential extraction of chromium indicates no readily available concentrations in the F1 and F2 fractions (table 16, at the back of this report; fig. 11). This finding is consistent with the F1 and F2 extraction for six marine sediment samples in Hong Kong (Choi and others, 2006). The F3 fraction ranged from 0.80 to 52.4 mg/kg and accounted only for 12.5 percent of chromium in all samples. Most of the chromium tended to be tightly bound and rather insoluble as evidenced by the F4 and F5 fractions. The F4 and F5 fractions concentrations ranged from 2.51 to 30.6 mg/kg and 7.49 to 54.7 mg/kg, respectively. In these samples, 20 percent of the chromium is associated with organic matter and 67 percent is associated with the mineral content. Because iron concentrations were quite large in all samples, it is possible that insoluble secondary oxidation minerals were formed in these sediments. Iron augmentation of contaminated soils and sediments has been shown to be a feasible remediation practice (Kumpiene and others, 2006). The mechanism for secondary mineral forma-

tion with zero-valent iron is described in Sastre and others (2004). This iron-trace element relation could have a substantial effect on the mobility of arsenic, vanadium, and cadmium, but has been shown to have little effect on reducing the mobility of copper (Kumpiene and others, 2006).

Copper was detected in all sequential extraction fractions; however, only one sample had a concentration of 33.7 mg/kg in the F1 fraction (table 17, at the back of this report; fig. 11). It is not clear why this single sample is different from the others, but it does suggest that the copper present in these samples can not be easily mobilized in natural waters. In the F2 fraction, 34 samples had concentrations ranging from 0.42 to 183 mg/kg. Generally, 11.6 percent of copper exists in a readily available form bound to carbonates in the sediment. All 51 samples had Cu concentrations bound to iron-manganese oxides in the F3 fraction. This fraction ranged from 0.10 to 60.5 mg/kg and accounted for only 7.5 percent of the total average concentration. The F4 fraction measured substantially larger than the F3 fraction and ranged from 1.02 to 716 mg/kg. The F4 fraction represented 45.8 percent of the average copper concentration, indicating that most of the copper in samples from southern Louisiana is associated with organic matter, a finding that is consistent with Pardo and others (1990). Stumm and Morgan (1981) proposed that copper easily can form complexes with organic compounds that make them rather stable in the aquatic environments. The F5 fraction ranged from 6.41 to 156 mg/kg. Generally, 37.8 percent of the copper in all 51 samples is associated with the crystalline matrix of the sediment samples.

Arsenic concentrations were limited to fractions F2-F5 (table 18, at the back of this report; fig. 11). In the F2 fraction, 44 of 51 samples had concentrations ranging from 0.30 to 2.35 mg/kg. This fraction accounted for 2.6 percent of the average concentration in all samples, and demonstrates a stronger affinity for arsenic to bind with the iron-manganese oxides of the F3 fraction and form insoluble secondary oxidation minerals with iron of the F5 fraction. The F3 fraction had a concentration range from 2.05 to 39.7 mg/kg, and represented 51 samples. This fraction accounted for 54.5 percent of the average concentration of all samples, indicating arsenic can be mobilized should anoxic conditions exist. In open oxidative conditions however, such as the case in the New Orleans environment following Hurricanes Katrina and Rita, arsenic would likely remain tied to the iron-manganese oxides. If arsenic were to be transported to other environments, such as the bottom of Lake Pontchartrain or the drainage canals, the environmental conditions could become reductive enough to mobilize a substantial part of this fraction with time. The F4 fraction concentration ranged from 0.10 to 10.2 mg/kg, and represented 46 of 51 samples. Whereas the potential for arsenic to be bound to organic matter exists, the F4 fraction suggests that this will occur only about 6.9 percent of the time. All 51 samples had concentrations ranging from 1.87 to 30.3 mg/kg in the F5 fraction, representing 37.2 percent of this trace element in the sediment samples.

Sequential extraction analysis of cadmium proved to be problematic. The distribution of cadmium data among the five fractions and the inconsistent number of samples where concentrations were observed are shown in figure 16. The largest concentration (2.39 mg/kg) was detected in the F3 fraction (table 19, at the back of this report). The F3 and F4 fraction had concentrations in 12 samples, whereas, the F1, F2, and F5 fractions had concentrations in 3, 10, and 3 samples, respectively. Whereas the presence of cadmium in post-Katrina samples was somewhat sporadic and small within the five fractions, these results seem to be consistent with those results observed by Choi and others (2006) for six marine sediments in Hong Kong. If the cadmium concentrations are truly representative of the post-Hurricane sediments, then there is little concern for mobility during any possible environmental change or handling process.

Analysis of iron was a decision made by the team following the trace element sequential analysis. Because of this, only limited quantities of sample remained for analysis; nevertheless, enough material remained to perform analysis on all 51 samples. Sequential extraction of these samples yielded expected and interesting results (fig. 11). None of the 51 samples had concentrations above the MDL of 15.0 mg/kg in the F1 fraction. In the F2 fraction, 34 samples had concentrations above the MDL, ranging from 17.0 to 1,750 mg/kg (table 20, at the back of this report; fig. 11). This indicates that about 0.9 percent of the total iron concentration in samples is associated with carbonates. The F3 fraction contained about 21 percent of the iron concentration, indicating that a substantial part of the iron is in the form of oxides. The F3 concentrations ranged from 282 to 20,596 mg/kg. All 51 samples had measurable concentrations of iron in the F4 fraction, ranging from 197 to 8,858 mg/kg. Iron complexed with organic matter accounted for 10.1 percent of the total detected in these samples. The residual F5 fraction contained about 67.1 percent of the total iron concentration. This indicates that iron is contained within various inorganic crystalline states that are not likely to become soluble under normal environmental conditions.

## Pesticide and Polychlorinated Biphenyl Results

The destruction caused by both hurricanes included the dispersion of organic chemicals throughout New Orleans and the Delta. The field teams observed many oil slicks that deposited at high water mark areas, fallen power lines, and broken transformers. The organic chemical contents from local businesses and homes strewn about the landscape also were apparent (fig. 12). Analysis of the environmental samples was targeted towards the organic compounds thought to be available to sediments in the affected region. In a preliminary study of these environmental sediment samples, 46 samples were analyzed for 18 pesticide compounds and benzene, toluene, ethylene, and xylene (BTEX). Results indicated that small concentrations of pesticides were observed in the sediments, with the dominant pesticide being methoxychlor. Of the BTEX

compounds, benzene was observed 78 percent of the time at concentrations near the method detection limit of 10.0  $\mu\text{g}/\text{kg}$  (Adams and others, 2007). Using the results of this preliminary investigation, the remaining samples were subjected to a more refined analysis to include the pesticides prometon, simazine, atrazine, heptachlor, and methoxychlor. In addition, the polychlorinated biphenyl (PCB) arochlors, 1016, 1221, 1232, 1242, 1248, 1254, and 1260 were measured.

## Pesticides in Sediment

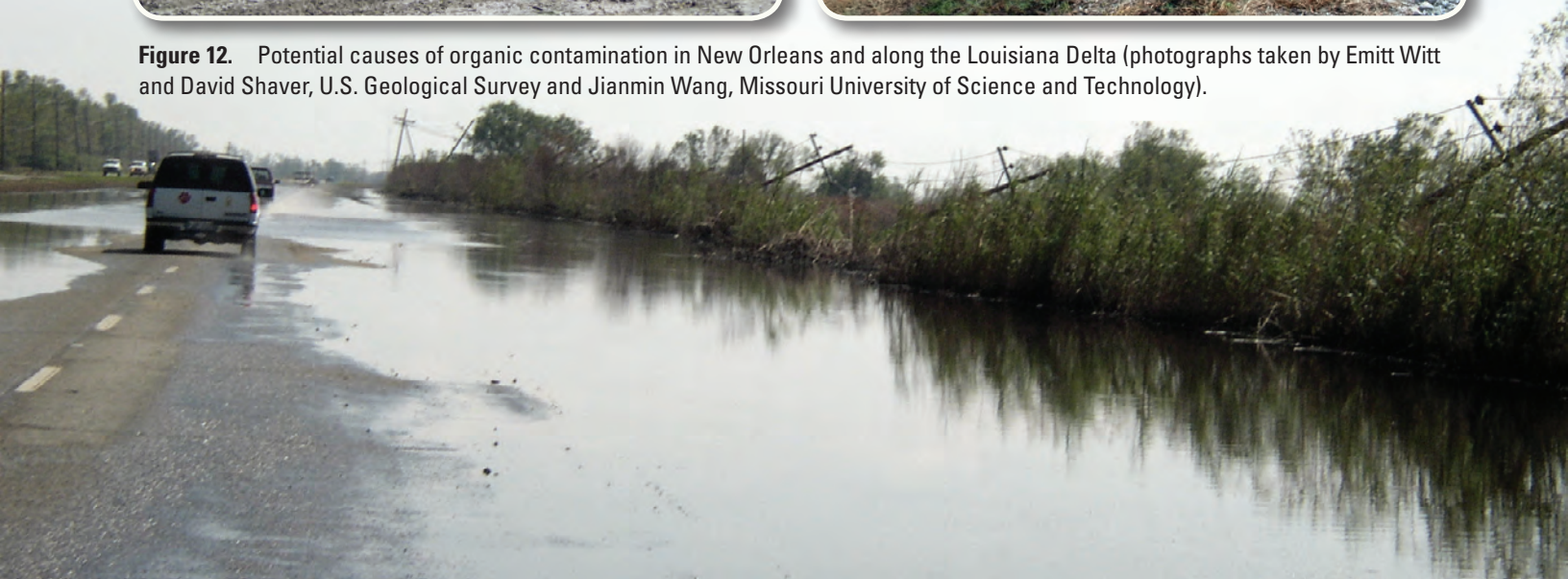
Five pesticide compounds including prometon, simazine, atrazine, heptachlor, and methoxychlor were measured in 157 environmental sediment samples (tables 21 and 22, at the back of this report). Only four of these compounds had detectable concentrations using the GC-ECD analysis method. Of these four compounds, atrazine had a single measurable concentration of 547  $\mu\text{g}/\text{kg}$ ; methoxychlor had three measurable concentrations ranging from 37.5 to 49.3  $\mu\text{g}/\text{kg}$ ; and heptachlor had five measurable concentrations ranging from 2.42 to 17.4  $\mu\text{g}/\text{kg}$  (table 21). Prometon could not be measured using GC-ECD because of a lack of electron affinity group of the chemical. The GC-MS method was applied to 42 of 157 samples to confirm and refine the results from the GC-ECD analysis. Results of this analysis indicates that 26 samples contained measurable prometon concentrations ranging from 2.4 to 193  $\mu\text{g}/\text{kg}$ ; 22 samples contained measurable methoxychlor concentrations ranging from 3.50 to 3,510  $\mu\text{g}/\text{kg}$ ; 20 samples contained measurable atrazine concentrations ranging from 4.4 to 187  $\mu\text{g}/\text{kg}$ ; 7 samples contained measurable simazine concentrations ranging from 4.80 to 82.4  $\mu\text{g}/\text{kg}$ ; and 7 samples contained measurable heptachlor concentration ranging from 2.90 to 33.3  $\mu\text{g}/\text{kg}$  (table 22).

Methoxychlor was reported in an earlier investigation to be the pesticide of concern (Adams and others, 2007). Methoxychlor is a diphenylalkane insecticide used to control flies, mosquitoes, cockroaches, and chiggers and is used on food crops, farm animals, pets, and in home gardens (Agency for Toxic Substance and Disease Registry, 1995). This insecticide has not been proven to cause cancer, but it can enter the body through direct contact with the skin. Methoxychlor may be related to developmental and reproductive effects, so its presence in flood-water sediments should be a concern to repopulating residents and recovery workers (Agency for Toxic Substance and Disease Registry, 1995). Common pathways for contact include handling contaminated food, water, and soil. Using methoxychlor as insect control along the southern coast may be largely responsible for the wide distribution of this compound in samples.

Methoxychlor is persistent in soils; it degrades slowly in aerobic conditions and more quickly in anaerobic environments. The World Health Organization (WHO) tolerable daily intake (TDI) guideline for methoxychlor in soils is 5.00  $\mu\text{g}/\text{kg}$  body weight/day (World Health Organization, 1996). To achieve this level, one would need to consume approximate 100 g of sediment contaminated at the highest concentra-



**Figure 12.** Potential causes of organic contamination in New Orleans and along the Louisiana Delta (photographs taken by Emmitt Witt and David Shaver, U.S. Geological Survey and Jianmin Wang, Missouri University of Science and Technology).



tion present (3,510 µg/kg) per day. Further, this maximum concentration of methoxychlor is orders of magnitude below the high-priority screening levels of 3,100,000 µg/kg cited by the USEPA for residential soil (U.S. Environmental Protection Agency, 2006b). Thus, the levels observed in the samples analyzed from New Orleans and the Louisiana Delta appear to be well within the acceptable limits.

Herbicide compounds, particularly the triazine class compounds, have been studied extensively in the Mississippi River and along Gulf Coast because of their potential effects on the Delta's productivity. Clark and Goolsby (2000) measured 271 water samples during the 1990's to determine the seasonal and annual discharge of triazines to the Gulf of Mexico via the Mississippi River. Their study primarily considers the mobile or dissolved phase of these compounds, but demonstrates large quantities of pesticides are being transported from the rich farm country of the northern Mississippi Valley. The Clark and Goolsby (2000) study specifically studies the relation of the increased loading of atrazine with increasing discharge during the growing season of May through August with more than 640 metric tons being transported annually. McMillin and Means (1996) measured the quantity of triazine pesticides in dissolved, colloidal, particulate phases, and sediment. Their results indicate that more frequent detections were observed in the dissolved and colloidal phases, with atrazine being the dominant compound and having the largest concentration. Studies involving the adsorption of atrazine have indicated that this compound has a favorable adsorption coefficient that allows it to be associated with clay minerals, sediment, and soil with large concentrations of amorphous iron and aluminum oxides and organic matter (Huang and others, 1984; Godskensen and others, 2005; Chefetz and others, 2004; Weber and others, 2004). Schwab and others (2006) indicate that surface sediment and soil are the more preferential adsorption sites for atrazine; however, adsorption accounts only for a small part of the total atrazine moving through the subsurface. These studies seem to confirm the findings of the post-Hurricane Katrina and Rita samples where few samples actually contained measurable concentrations of atrazine and simazine. This indicates that the large annual discharge of triazine compounds has a small total effect on the concentrations of these compounds in the Gulf Coast sediment. The fact that any of these compounds were observed in post-hurricane samples may indicate the possibility of local introduction of these compounds resulting from the Hurricanes' impact on the regional infrastructure. The Hurricanes' impacts would have been responsible for scattering local stores of these chemicals or the redistribution of sediment from local agricultural operations that use these herbicides.

### Polychlorinated Biphenyl in Sediment

Polychlorinated biphenyls (PCB) were measured using the GC-ECD method only. Insufficient amounts of sample remained to use the GC-MS method which, in hindsight, may have been the more appropriate method of analysis for PCBs. There were

no detectable concentrations of Aroclor 1016, 1221, 1232, 1242, 1248, 1254, and 1260 above the MDLs for any environmental sample (table 21, at the back of this report). Because of the high background of the sample, 39 of 157 samples were not analyzed; these samples are reported as non-detects (ND).

PCBs have been detected in small concentrations in sediments of the Gulf of Mexico and in sediments to the east of the Mississippi River (Sericano and others, 1989). Whereas the post-hurricane PCB study is inconclusive, it may be an important consideration for future studies where adequate sample is acquired under more rigorous field quality assurance procedures.

## Summary and Conclusion

The results of this study represent the chemical characteristics of perishable soil and sediment samples obtained from New Orleans and the Louisiana Delta following the destruction of the 2005 storm season. Gathering the samples within one month after Hurricanes Katrina and Rita, the team was given the opportunity to catalog the effects the storms had on the landscape before the debris and deposited sediments were removed from the affected area. A maximum of 157 of the remaining samples were analyzed for single extraction trace elements and iron, sequential extraction of trace elements and iron, pesticides, and PCB Aroclor congeners. Some of the original 238 samples were field duplicates, samples of oil stained vegetation, and samples that would otherwise not contribute to the hurricane deposited sediment discussion; therefore, these samples were not analyzed for nor discussed in this report.

Extensive quality assurance procedures were used during laboratory analysis to provide the highest quality database possible. In some cases, alternative analytical techniques were used to confirm or refine the results of earlier analyses. Such was the case with the environmental samples analyzed for pesticides. Nearly 35 percent of the analytical effort was dedicated to analysis of blanks, duplicates, and matrix spikes.

Chemical concentrations were measured for Cu, Pb, As, Cd, Hg, Cr, V, and Fe using a single extraction procedure defined by U.S. Environmental Protection Agency (USEPA) methods. In decreasing order, the largest range in constituent concentration variability was observed for Pb, V, Cr, Cu, As, Cd, and Hg. Lead, arsenic, and mercury were elements of interest in this study because of the potential for toxic effects on repopulating residents and debris removal crews. The large lead concentrations that were observed in samples are consistent with pre-hurricane studies of New Orleans soils. This indicates that lead concentrations may not be the result of hurricane debris mixing with sediments, but may be from redistribution of existing lead-contaminated sediment. Nevertheless, lead is expected to be at hazardous levels for repopulating residents, debris removal crews, and to children who come into contact with New Orleans soils. Arsenic concentration exceeded the USEPA Region 6 HHMSSL cancer level of



0.39 mg/kg in all samples. Additionally, 7 samples contained arsenic concentrations above the larger non-cancer screening level. Mercury data for these post-hurricane samples was compared with the USGS NGS regional data, and determined to have significantly larger concentrations; however, all of the concentrations were significantly below HHMSSL. Vanadium, chromium and cadmium pose little danger to New Orleans and Louisiana Delta residents at concentration levels observed in this study. Elemental concentrations of iron in post hurricane samples are large and consistent with results of earlier research. Iron showed a strong relationship with arsenic, chromium, and vanadium, but did not correlate well with the other trace elements.

To further investigate the nature of the trace elements and iron in environmental soil and sediment samples, 51 of 157 samples were selected for a sequential extraction procedure to understand the form in which each element exists. Mercury was not included in this procedure because of low levels detected in the single-extraction method and the potential for contamination in any one of the extraction steps. Because of low levels in the samples, cadmium concentrations were inconclusive in this analysis and caution should be exercised whenever these results are used. The residual component of the determination, or that which represents the concentration of an element that is associated with the immobile crystalline structure of the sample matrix, was the dominant form in which vanadium, copper, chromium, and iron were detected in these post-hurricane samples. Arsenic and lead predominantly were contained in the iron-manganese oxides of samples. Lead was the only element to have a substantial percentage of its total concentration in the highly mobile exchangeable and carbonate fractions. Based on these sequential extraction results, and in consideration of the previous research done on this element in soils of New Orleans, lead could be considered the most problematic trace element measured in the study, and poses the greatest threat to the clean up and repopulation of New Orleans.

Pesticides in soil and sediment samples generally were small with some exceptions. Methoxychlor was the largest concentration measured and was detected in 22 of 157 samples measured for organic compounds. The presence of methoxychlor in these samples does not pose a health threat at any level measured in this study. Smaller concentrations of atrazine, prometon, simazine, and heptachlor also were observed in samples from New Orleans and the Louisiana Delta. The presence of these compounds in the reported concentrations is not a primary concern to repopulating residents.

Polychlorinated biphenyl Arochlor congeners were measured but not observed above the method detection limits for any of the analyzed samples. There were several samples that had large background matrix interference problems. These samples are reported as non-detects in the dataset. Although the overall results are not conclusive, the PCB dataset indicates that they are not compounds of concern in sediments and soils of post-hurricane Louisiana.

Deploying to an area recently ravaged by a natural disaster always creates a large degree of uncertainty for an investi-

gative team. Working under these demanding circumstances forced the team to be adaptive in planning and executing new data-collection methods. Given the complexity of responding to any natural disaster, the collection of perishable data may not always conform to rigorous statistical sampling schemes or even established sample collection procedures that have been proven to ensure representativeness and quality during normal study conditions. The conditions surrounding data collection in this study were complex, and unforgiving; however, every effort was made to enlist the best talent, highest-quality equipment, and most rigorous procedures given the challenges of sampling among the post-hurricane chaos. Every scientific investigation that was performed following these devastating hurricanes provides the scientific community with a unique opportunity to document lessons learned. In an effort to aid recovery and response efforts in the future, these should be used to compile a standardized methods manual. The research and analytical efforts employed by the USGS and Missouri S&T team provides an essential contribution to that cause. Additionally, the research results herein provide vital information to resource managers, debris removal personnel, and the repopulating residents of southern Louisiana. Finally, no one could have predicted the vast destruction left after nature wrecked havoc on New Orleans and the Louisiana Delta; though no one can erase the past, the chemical status of post-hurricane sediments described in this report can help ensure a safer tomorrow for all of Louisiana's residents.

## Acknowledgments

This work was sponsored by hurricane supplemental funds allocated to the U.S. Geological Survey, Mid-Continent Geographic Science Center, through the Geographic Analysis and Monitoring Program, to facilitate the collection of perishable engineering and environmental data in cooperation with the Missouri University of Science and Technology Natural Hazard Mitigation Institute following Hurricanes Katrina and Rita. Analyses and additional support was provided by the Environmental Research Center for Emerging Contaminants at the Missouri University of Science and Technology. Special thanks to the OCSNER Medical Group of New Orleans for allowing the team to use its administrative facility as a base of operations for this effort. Also, special thanks to Calvin O'Neal and the U.S. Geological Survey, National Wetland Science Center, Lafayette, Louisiana, for providing temporary housing for the deployed team. Furthermore, this effort could not have been conducted without field-level data collection, laboratory, and GIS support from Adam Sevi, Connor Watkins, David Summers, Neil Anderson, Ronaldo Luna, David Shaver, Youssef Filali-Meknassi, Tingzhi Su, David Kaufman, Michael Starbuck, David Rogers, Shi Shu, and Jie Ding.

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# Tables

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SEA



**Table 13.** Results of single extraction analysis for trace elements and iron from sediment and soil collected following Hurricanes Katrina and Rita, 2005.

[All concentrations in units of milligram per kilogram; --, not tested; ND, no detection]

Sample number	Latitude	Longitude	pH	Percent moisture	Vanadium	Chromium	Copper	Cadmium	Lead	Arsenic	Mercury	Iron	Percent total organic carbon (in dry soil)	Percent inorganic carbon (in dry soil)
1	30.0294	90.2171	8.1	5.26	19.4	10.6	8.04	0.20	46.6	4.55	0.09	10,000	1.70	--
2	30.0294	90.2171	7.1	15.9	30.7	19.6	14.1	0.17	12.0	4.92	0.08	15,000	1.45	--
3	30.0294	90.2171	7.2	32.1	20.4	11.2	15.8	0.18	27.7	3.15	0.14	8,190	5.08	--
4	30.0294	90.2171	7.8	12.3	22.6	14.5	8.84	0.15	20.7	3.65	0.07	9,060	1.70	0.13
5	30.0207	90.2049	7.7	19.2	21.0	13.0	6.59	0.15	30.1	2.40	0.08	7,250	1.34	--
6	30.0207	90.2049	7.4	30.1	17.1	14.2	4.82	0.16	11.0	2.60	0.09	7,300	2.62	--
7	30.0207	90.2049	7.2	6.3	41.3	22.1	16.0	0.27	23.7	9.95	0.13	17,300	2.38	--
8	30.0207	90.2049	6.9	30.5	28.2	19.1	9.86	0.20	15.7	3.90	0.09	10,800	3.34	--
9	30.0207	90.2049	7.6	8.00	22.5	13.2	6.74	0.18	9.59	3.13	0.12	10,300	1.20	--
10	30.0162	90.1981	7.2	26.0	54.8	33.4	28.1	0.48	30.3	8.16	0.09	22,400	4.66	--
11	30.0162	90.1981	7.2	12.2	42.0	23.6	16.8	0.28	151	8.71	0.10	17,700	3.90	--
12	30.0162	90.1981	8.5	1.02	28.6	17.8	8.80	0.20	28.5	4.23	0.07	11,700	1.01	0.14
13	30.0153	90.1631	--	1.58	27.9	18.3	12.6	0.19	44.2	4.56	0.18	10,100	2.00	--
14	30.0153	90.1631	5.6	12.8	75.4	50.6	960	1.17	77.0	14.6	0.12	22,700	14.8	--
15	30.0153	90.1631	6.7	10.9	55.9	33.4	45.4	1.36	67.5	8.13	0.29	17,200	11.0	--
16	30.0178	90.1204	--	39.7	57.8	30.9	38.2	0.93	80.6	11.7	0.14	21,000	--	--
17	30.0178	90.1204	7.4	34.6	44.1	23.7	27.0	0.41	82.9	7.23	0.20	16,400	3.53	--
18	30.0178	90.1204	7.6	28.0	50.8	28.5	38.0	0.53	141	8.64	0.37	18,700	3.20	0.17
19	30.0178	90.1204	7.6	18.3	44.3	22.3	14.2	0.28	24.5	7.10	0.09	15,700	0.01	1.77
20	30.0178	90.1204	7.8	16.7	43.7	21.7	12.6	0.23	13.9	5.43	0.07	16,100	0.31	0.43
21	30.0178	90.1204	--	18.1	36.9	21.0	223	0.47	111	9.73	0.36	17,400	--	--
22	30.0178	90.1204	7.4	13.6	28.4	15.6	19.5	0.25	93.5	4.06	0.30	10,600	2.48	--
23	30.0169	90.1137	6.4	24.9	34.3	18.3	36.0	0.41	86.2	6.53	0.22	12,800	5.63	--
24	30.0169	90.1137	7	23.1	24.5	13.9	15.6	0.23	35.0	5.04	0.18	9,090	4.42	--
25	30.0169	90.1137	7.1	17.4	29.6	17.6	13.5	0.25	29.2	3.91	0.11	12,000	2.78	--
26	30.0196	90.1073	5.7	11.9	23.0	18.7	20.6	0.45	495	33.7	0.31	9,400	11.2	--
27	30.0196	90.1073	6.3	17.3	30.8	19.1	10.5	0.19	123	3.99	0.12	11,700	3.03	--
28	30.0170	90.1067	7.1	76.3	23.7	13.6	20.7	0.51	354	5.18	0.37	--	17.9	--
29	30.0170	90.1067	6.2	22.0	51.8	24.7	28.1	0.45	155	27.9	0.79	15,070	3.53	--
30	30.0170	90.1067	5.6	12.5	25.1	12.5	11.4	0.36	42.2	25.2	0.45	7,800	2.68	--

**Table 13.** Results of single extraction analysis for trace elements and iron from sediment and soil collected following Hurricanes Katrina and Rita, 2005.—Continued

[All concentrations in units of milligram per kilogram; --, not tested; ND, no detection]

Sample number	Latitude	Longitude	pH	Percent moisture	Vanadium	Chromium	Copper	Cadmium	Lead	Arsenic	Mercury	Iron	Percent	
													total organic carbon (in dry soil)	inorganic carbon (in dry soil)
31	30.0039	90.1140	7.3	7.05	82.5	46.4	64.5	2.05	137	23.1	0.26	37,200	4.90	--
32	30.0039	90.1140	7.2	20.0	38.6	19.5	34.3	0.28	99.8	5.15	0.48	12,500	2.29	--
33	30.0039	90.1140	7.9	15.9	42.4	21.8	22.4	0.27	128	6.46	0.61	13,600	1.65	0.10
34	30.0039	90.1140	7.7	3.93	52.6	30.1	36.6	0.65	75.7	12.5	0.23	24,000	4.59	--
35	30.0039	90.1140	7.6	12.7	19.1	12.8	7.31	0.14	28.8	2.44	0.14	7,470	2.09	--
36	30.0039	90.1140	6.7	20.4	36.5	19.9	23.2	0.36	81.6	13.5	0.31	13,700	15.6	--
37	30.0039	90.1140	6.8	9.58	19.6	9.66	5.46	0.14	11.7	3.73	0.09	8,250	1.17	--
38	30.0039	90.1140	6.1	7.96	19.2	12.1	5.89	0.14	14.2	3.51	0.08	8,930	0.73	--
39	30.0122	90.0692	4.2	6.07	18.8	22.3	46.6	0.69	187	4.48	0.80	6,710	9.46	--
40	30.0107	90.0687	6	6.98	9.91	0.59	12.7	0.30	83.7	1.92	0.63	3,050	0.72	--
41	30.0100	90.0673	4.5	26.0	18.8	23.5	40.6	0.72	244	7.04	0.60	7,960	1.91	--
42	30.0095	90.0681	7.2	8.15	5.70	3.63	2.77	<0.06	16.6	0.84	0.34	1,530	0.62	--
43	30.0095	90.0687	7.4	21.5	8.03	4.57	3.49	<0.06	35.5	1.04	0.50	2,380	0.53	--
44	30.0086	90.0665	7.5	2.43	60.0	44.9	56.2	1.09	220	10.5	0.50	22,800	3.56	--
45	30.0086	90.0665	7.2	2.53	53.5	42.0	54.4	1.01	216	9.43	0.49	21,500	4.11	--
46	30.0085	90.0687	7.2	26.6	44.5	21.3	18.5	0.15	28.4	4.10	0.09	15,300	0.95	--
47	30.0081	90.0694	3.8	22.2	36.2	22.9	21.3	1.80	129	4.95	0.32	10,300	4.87	--
48	30.0256	90.0231	4.7	26.4	27.5	17.8	27.7	2.11	199	5.11	0.47	9,350	11.7	--
49	30.0256	90.0231	3.8	23.9	20.7	9.32	10.6	0.49	42.3	2.17	0.37	5,390	11.3	--
50	30.0256	90.0231	--	19.9	31.1	15.7	15.3	0.25	43.4	3.30	0.20	14,400	4.79	--
51	30.0256	90.0231	6.8	17.8	34.1	16.3	11.8	0.24	32.9	3.80	0.13	14,400	2.26	--
52	30.0256	90.0231	7.3	2.45	13.0	7.17	14.0	0.39	24.2	2.71	0.29	4,320	4.39	--
53	30.0491	89.9804	7.4	16.4	18.8	8.96	6.22	0.21	14.3	2.31	0.18	7,120	3.09	--
54	30.0491	89.9804	7	22.1	28.4	14.2	13.4	0.19	40.3	2.79	0.30	13,800	4.36	--
55	30.0491	89.9804	7.2	18.6	50.7	28.4	22.1	0.49	34.5	3.49	0.13	17,900	1.90	--
56	30.0586	89.9662	7.2	18.3	19.0	14.7	9.15	0.18	20.3	3.78	0.12	5,960	3.83	--
57	30.0586	89.9662	7.3	6.85	26.9	19.4	12.0	0.28	54.1	3.62	0.12	7,480	2.59	--
58	30.0586	89.9662	7.3	12.4	25.4	16.6	8.82	0.21	38.4	6.93	0.10	9,140	3.18	--
59	30.0608	89.9591	6.9	20.2	23.1	12.1	8.77	0.19	9.2	3.47	0.13	7,030	2.22	--
60	30.0608	89.9591	6.9	24.3	30.2	17.4	11.3	0.16	22.0	2.71	0.12	6,280	8.14	--



**Table 13.** Results of single extraction analysis for trace elements and iron from sediment and soil collected following Hurricanes Katrina and Rita, 2005.—Continued

[All concentrations in units of milligram per kilogram; --, not tested; ND, no detection]

Sample number	Latitude	Longitude	pH	Percent moisture	Vanadium	Chromium	Copper	Cadmium	Lead	Arsenic	Mercury	Iron	Percent total organic carbon (in dry soil)	Percent inorganic carbon (in dry soil)
61	30.0608	89.9591	6.6	26.0	19.6	11.2	6.46	0.13	11.3	1.59	0.09	4,520	4.12	--
62	30.0572	89.9558	7.7	20.8	52.0	24.6	18.4	0.28	19.1	8.26	0.06	17,600	2.61	0.15
63	30.0572	89.9558	7.8	14.1	20.1	18.0	11.1	0.35	59.5	3.59	0.32	6,390	0.71	4.92
64	30.0572	89.9558	7.3	12.6	24.2	58.8	7.22	0.18	17.7	3.26	0.10	7,100	2.23	--
65	30.0572	89.9558	7.5	62.7	57.3	20.8	15.7	0.35	17.4	22.8	ND	35,080	7.50	0.72
66	30.0477	89.9620	6.2	12.7	56.1	30.8	18.8	0.26	30.4	12.0	0.07	14,100	3.18	--
67	30.0477	89.9620	7.2	17.0	21.7	17.0	16.8	0.21	36.8	3.91	0.15	6,480	2.64	--
68	30.0477	89.9620	7.5	10.7	13.1	12.1	9.96	0.18	30.2	3.04	0.15	4,790	2.41	0.09
69	30.0446	89.9601	7.3	1.46	14.4	11.0	2.73	0.07	4.55	2.23	0.05	6,640	0.26	--
70	30.0446	89.9601	7.9	8.90	18.0	11.1	14.1	0.13	6.16	3.02	0.09	9,360	1.10	--
71	30.0446	89.9601	7	13.8	24.3	13.2	10.6	0.17	10.1	2.92	0.08	9,090	3.39	--
72	30.0446	89.9601	7.1	18.0	45.5	25.4	84.5	0.80	189	5.37	0.13	16,000	4.29	--
73	30.0446	89.9601	7.3	19.4	48.6	27.2	42.7	0.53	85.9	7.36	0.09	19,100	1.23	--
74	30.0398	89.9510	7.3	17.2	60.0	60.8	85.5	1.48	249	15.8	0.02	27,800	3.36	--
75	30.0398	89.9510	6.6	20.2	16.0	12.3	6.60	0.29	8.99	2.61	ND	4,300	2.46	--
76	30.0398	89.9510	6.7	15.8	48.4	43.3	106	1.07	263	15.3	0.39	19,300	6.13	--
77	29.9788	90.1308	6.1	19.7	30.5	16.0	31.0	0.37	114	3.93	0.18	11,330	2.86	--
78	29.9788	90.1308	6.8	28.9	34.1	19.3	37.0	0.39	63.8	4.06	0.19	9,710	6.54	--
79	29.9766	90.1318	7.1	6.91	42.7	22.1	17.0	0.53	95.4	5.59	0.17	13,200	2.81	--
80	29.9766	90.1318	6.8	26.9	20.0	13.8	8.54	0.16	17.4	3.64	0.11	7,120	9.45	--
81	29.9766	90.1318	6.5	8.88	13.9	10.3	7.95	0.16	11.2	2.35	0.13	5,670	10.9	--
82	29.9766	90.1318	6.7	8.95	25.0	22.3	13.1	0.37	98.1	3.68	0.23	8,460	3.47	--
83	29.9513	90.1100	6.8	15.4	32.9	20.7	18.8	0.53	147.3	4.98	0.27	11,200	3.51	--
84	29.9463	90.1076	7.3	0.90	18.3	12.3	4.86	0.16	7.55	3.98	0.08	7,430	1.30	--
85	29.9412	90.1034	--	3.72	29.6	16.1	12.5	0.20	22.6	5.55	0.11	9,660	--	--
86	29.9424	90.0967	7.4	6.71	17.0	17.3	51.5	2.01	551	4.18	1.30	9,490	17.0	--
87	29.9773	90.0173	7.4	63.5	86.0	45.9	35.8	0.84	42.4	12.2	0.04	26,900	5.37	--
88	29.9786	90.0169	7.7	47.1	61.8	35.8	28.6	0.76	46.3	8.20	0.09	19,100	4.03	0.78
89	29.9777	90.0110	7.1	56.1	67.3	37.9	36.3	1.47	51.6	11.1	0.13	22,300	5.87	--
90	29.9744	90.0104	6.5	49.2	81.2	45.3	40.2	1.62	53.3	12.1	0.08	30,900	5.12	--

**Table 13.** Results of single extraction analysis for trace elements and iron from sediment and soil collected following Hurricanes Katrina and Rita, 2005.—Continued

[All concentrations in units of milligram per kilogram; --, not tested; ND, no detection]

Sample number	Latitude	Longitude	pH	Percent moisture	Vanadium	Chromium	Copper	Cadmium	Lead	Arsenic	Mercury	Iron	Percent	
													total organic carbon (in dry soil)	inorganic carbon (in dry soil)
91	29.9731	90.0109	6.1	52.8	76.3	38.8	32.6	0.63	34.2	11.3	0.05	26,300	5.50	--
92	29.9694	90.0121	--	4.85	62.9	36.6	32.9	0.61	34.9	11.1	0.13	27,200	4.76	--
93	29.9686	90.0197	7.4	3.72	50.0	25.4	21.6	0.26	26.7	6.06	0.17	25,200	4.30	--
94	29.9686	90.0197	--	34.8	42.1	20.0	15.1	0.19	16.2	5.09	0.09	21,900	--	--
95	29.9686	90.0197	6.9	42.3	68.2	33.0	22.6	0.45	25.0	9.11	0.11	33,600	5.44	--
96	29.9686	90.0197	--	60.0	63.5	29.0	23.8	0.32	22.3	7.01	0.04	30,800	7.09	--
97	29.9691	90.0211	7.5	24.4	48.6	22.7	28.9	0.51	141	12.4	0.09	17,700	4.75	--
98	29.9644	90.0260	7.7	4.21	71.3	40.6	47.1	0.81	62.2	11.3	0.14	11,200	4.66	--
99	29.9701	90.0229	7.5	35.0	81.9	43.9	33.5	0.67	49.8	11.5	0.07	23,100	2.29	0.32
100	29.9701	90.0229	7.5	34.3	56.5	26.5	25.6	1.14	30.2	11.6	0.09	16,600	2.88	0.52
101	29.9699	90.0229	7.4	7.04	59.3	28.9	30.3	0.58	35.3	11.4	0.12	18,100	3.28	--
102	29.9703	90.0230	7.4	43.7	64.2	37.1	34.0	0.79	63.0	9.65	0.08	20,100	4.37	--
103	29.9834	89.9445	--	1.76	11.0	8.75	3.96	0.15	4.47	1.64	0.10	3,370	5.74	--
104	29.9834	89.9445	6.8	62.2	88.2	43.4	26.9	0.42	27.1	11.7	0.03	27,400	6.82	--
105	29.9834	89.9445	7.6	24.9	30.2	17.4	21.7	0.40	23.0	6.51	0.09	9,640	4.38	0.81
106	29.9490	89.9581	7.1	22.2	39.2	22.8	25.9	0.61	38.5	5.07	0.11	13,600	4.26	--
107	29.9490	89.9581	7.3	27.3	58.7	30.9	23.0	0.59	101	7.10	0.06	17,400	5.51	--
108	29.9490	89.9581	4.6	68.1	85.6	39.3	39.8	1.12	65.0	14.1	0.05	25,600	14.1	--
109	29.9510	89.9491	3.2	60.5	88.0	45.2	30.3	0.92	38.6	15.0	0.04	26,200	7.69	--
110	29.9510	89.9491	6.2	6.23	81.4	40.3	25.0	0.37	42.3	9.34	0.10	24,100	13.9	--
111	29.9510	89.9491	5	62.6	83.5	40.9	28.1	0.56	42.9	8.76	0.04	23,700	14.3	--
112	29.9474	89.9446	6.7	2.6	36.4	18.1	14.3	0.42	20.6	6.76	0.08	11,400	1.47	--
113	29.9474	89.9446	7	8.12	22.3	13.1	9.22	0.33	15.8	3.44	0.12	8,260	3.01	--
114	29.9474	89.9446	4	48.4	41.6	21.7	20.5	0.54	33.9	5.93	0.07	13,400	9.27	--
115	29.9455	89.9565	6.6	6.25	58.5	31.6	33.5	0.65	95.1	4.92	0.17	17,400	7.39	--
116	29.9455	89.9565	7.4	4.18	17.0	9.72	5.38	0.20	16.1	2.90	0.10	5,900	0.7	--
117	29.9455	89.9565	6.2	23.8	89.7	44.9	41.2	0.48	71.4	10.5	0.05	30,400	3.97	--
118	29.9438	89.9257	7.3	14.4	12.5	6.70	3.79	0.17	6.76	1.64	0.08	5,120	3.26	--
119	29.9438	89.9257	6	23.8	17.3	10.50	5.11	0.24	6.92	2.40	0.08	6,400	3.54	--
120	29.9438	89.9257	6.5	17.8	12.4	6.71	3.85	0.12	6.18	1.31	0.09	4,830	2.57	--

**Table 13.** Results of single extraction analysis for trace elements and iron from sediment and soil collected following Hurricanes Katrina and Rita, 2005.—Continued

[All concentrations in units of milligram per kilogram; --, not tested; ND, no detection]

Sample number	Latitude	Longitude	pH	Percent moisture	Vanadium	Chromium	Copper	Cadmium	Lead	Arsenic	Mercury	Iron	Percent total organic carbon (in dry soil)	Percent inorganic carbon (in dry soil)
121	29.9341	89.9444	7.5	16.1	41.4	20.1	14.0	0.24	26.0	6.38	0.07	16,100	1.74	--
122	29.9314	89.9459	7.9	14.0	51.1	30.7	21.6	0.63	32.5	21.2	0.16	20,000	1.99	--
123	29.9314	89.9459	7.9	6.25	41.4	24.6	20.9	0.39	23.2	12.0	0.15	17,800	1.15	--
124	29.9336	89.9678	7.9	10.1	17.2	24.9	12.2	0.26	85.3	20.7	0.04	8,400	1.92	--
125	29.9336	89.9678	8.3	10.2	11.8	17.0	7.08	0.18	56.4	6.90	0.18	3,850	2.46	3.41
126	29.9313	89.9689	8.2	11.3	11.9	ND	10.9	0.23	42.2	4.74	0.14	4,460	1.04	3.36
127	29.9313	89.9689	8.3	14.7	57.5	30.1	24.4	0.42	48.8	16.4	0.21	22,200	1.34	3.05
128	29.6703	89.9723	7.3	25.0	42.2	21.7	23.1	0.27	18.6	8.08	0.07	19,800	1.8	--
129	29.6703	89.9723	7.6	16.3	22.5	9.17	36.7	0.22	21.3	3.10	0.08	7,580	2.45	2.44
130	29.6703	89.9723	--	7.27	35.1	18.5	16.2	0.17	16.0	10.1	0.07	15,800	--	--
131	29.6703	89.9723	7.4	18.5	35.6	17.2	9.20	0.20	9.40	6.28	0.05	13,400	3.41	--
132	29.6703	89.9723	7.3	13.3	30.0	13.5	7.22	0.26	7.39	7.26	0.05	10,800	0.54	--
133	29.6703	89.9723	7.4	10.1	31.3	13.4	9.22	0.23	30.3	6.14	0.06	9,830	4.34	--
134	29.6703	89.9723	7.2	30.5	52.9	23.6	15.8	0.28	14.7	10.7	0.06	24,700	3.99	--
135	29.6703	89.9723	7.3	25.6	65.3	31.5	21.3	0.29	19.4	11.3	0.05	27,100	2.42	--
136	29.5004	89.7201	7.6	32.5	91.5	41.7	23.7	0.32	35.1	11.2	<0.02	26,500	2.67	0.55
137	29.4745	89.6879	7.3	23.0	39.5	20.1	16.1	0.23	19.0	6.13	0.14	17,000	1.92	--
138	29.4722	89.6854	7.3	16.8	40.5	38.3	53.2	0.69	249	49.1	0.31	17,300	2.05	--
139	29.4722	89.6854	7	44.6	46.2	22.5	21.7	0.56	18.7	6.23	0.15	16,000	7.46	--
140	29.4722	89.6854	7.8	19.1	25.8	17.0	32.6	0.10	25.8	4.28	0.16	21,900	0.95	--
141	29.4722	89.6854	7.5	35.0	46.3	24.3	43.2	0.22	58.3	6.88	0.15	21,400	6.61	--
142	29.4722	89.6854	6.8	47.9	74.8	81.2	125	4.30	72.3	26.9	0.03	56,200	2.88	--
143	29.4722	89.6854	5.6	36.0	12.9	6.50	20.2	0.35	18.3	5.80	0.35	19,700	3.64	--
144	29.3883	89.6050	7.5	21.2	48.1	23.8	16.8	0.30	41.4	4.16	0.06	11,700	2.33	0.19
145	29.3883	89.6050	7.6	29.7	61.8	25.6	19.7	0.22	18.5	6.65	<0.02	16,600	3.31	0.13
146	29.3675	89.5662	7.6	24.0	45.1	24.0	47.4	0.63	157	8.26	0.08	23,600	2.46	1.72
147	29.3630	89.5644	--	18.8	37.1	41.2	14.1	0.29	110	4.78	0.06	12,400	--	--
148	29.3630	89.5644	7.5	5.29	29.9	12.8	5.07	0.10	6.86	3.14	0.03	10,200	0.32	0.39
149	29.3528	89.5241	7.8	13.8	42.6	19.2	10.2	0.21	9.59	8.10	0.04	12,900	0.63	0.37
150	29.3528	89.5241	7.4	23.1	75.6	42.0	32.0	0.76	42.0	14.5	0.07	24,800	5.27	--

**Table 13.** Results of single extraction analysis for trace elements and iron from sediment and soil collected following Hurricanes Katrina and Rita, 2005.—Continued

[All concentrations in units of milligram per kilogram; --, not tested; ND, no detection]

Sample number	Latitude	Longitude	pH	Percent moisture	Vanadium	Chromium	Copper	Cadmium	Lead	Arsenic	Mercury	Iron	Percent total organic carbon (in dry soil)	Percent inorganic carbon (in dry soil)
151	29.3528	89.5241	7.2	28.7	85.2	44.8	26.7	0.53	29.0	13.0	0.04	26,200	6.30	--
152	29.3360	89.4952	7.6	33.1	69.0	35.7	25.9	0.54	50.2	7.67	ND	16,900	0.12	5.24
153	29.3360	89.4952	--	29.8	92.1	46.0	31.4	0.75	37.4	8.15	ND	20,500	--	--
154	29.3486	89.4625	7.2	17.7	16.2	13.3	14.3	0.40	20.7	4.36	0.90	5,700	3.86	--
155	29.3486	89.4625	7	23.9	76.3	46.2	30.1	0.59	42.7	8.80	0.07	23,700	3.44	--
156	29.3486	89.4625	7.2	24.1	85.1	49.0	30.6	0.74	36.5	9.33	ND	26,800	2.68	--
157	29.2713	89.3539	7.3	25.6	69.4	37.2	28.4	1.32	25.1	15.2	0.06	28,300	4.77	--

**Summary statistics**

Elements	Vanadium	Chromium	Copper	Cadmium	Lead	Arsenic	Mercury	Iron
Total Observations	157	156	157	155	157	157	150	156
Mean Concentration	90.0	7.0	21.1	40.36	23.6	30.26	0.48	15,100
25 percent Quartile	90.0	6.8	10.1	22.46	14.2	10.70	0.20	8,450
Median Concentration	90.0	7.2	18.1	36.45	20.8	18.83	0.32	13,700
75 percent Quartile	90.1	7.5	26.3	54.47	30.7	10.1	0.56	20,200
Minimum Concentration	89.46	3.20	0.90	5.70	0.59	2.73	0.07	1,530
Maximum Concentration	90.2	8.5	76	92.06	551.0	49.1	4.30	56,200
Standard Deviation	0.2	0.9	78.50	21.73	79.80	79.28	0.50	8,390
Variance	0	1	6,160	472.03	6,360	41.6	0.25	7.04x10 <sup>7</sup>

**Table 14.** Results of sequential extraction analysis for lead from sediment and soil collected following Hurricanes Katrina and Rita.

[mg/kg, milligram per kilogram; F1, exchangeable fraction; F2, bound to carbonate fraction; F3, iron and manganese oxides fraction; F4, organic matter fraction; F5, residual; <, less than]

Sample number	Location		Sequential Extraction fraction (mg/kg dry soil)						Single extraction (mg/kg dry soil)
	Latitude	Longitude	F1	F2	F3	F4	F5	Sum (F)	
10	30.0162	90.1981	<0.10	2.09	14.3	7.62	11.8	35.8	30.3
14	30.0153	90.1631	2.34	8.55	14.4	10.6	34.2	70.1	77.0
15	30.0153	90.1631	0.22	6.88	18.0	18.13	14.5	57.7	67.5
16	30.0178	90.1204	<0.10	10.8	42.7	8.22	17.1	78.7	80.6
26	30.0196	90.1073	88.4	108	175.3	169	53.7	595	495
29	30.0170	90.1067	2.42	8.86	56.2	38.8	38.6	145	155
30	30.0170	90.1067	5.08	4.20	15.6	5.03	7.93	37.8	42.2
31	30.0039	90.1140	0.21	14.61	41.8	17.2	36.4	110.18	137
34	30.0039	90.1140	0.30	5.82	25.3	17.7	24.0	73.1	75.7
36	30.0039	90.1140	3.60	6.23	36.17	29.3	17.6	92.9	81.6
44	30.0086	90.0665	2.51	41.2	94.4	21.6	60.0	220	220
65	30.0572	89.9558	<0.10	1.10	4.83	0.97	8.34	15.2	17.4
66	30.0477	89.9620	0.18	0.56	7.00	5.00	7.10	19.8	30.2
74	30.0398	89.9510	1.42	7.03	89.4	44.0	57.9	200	249
86	29.9424	90.0967	2.64	89.1	261	20.1	242.51	615	551
87	29.9773	90.0173	0.16	6.31	22.8	4.07	10.8	44	42.4
88	29.9786	90.0169	<0.10	7.96	26.2	5.99	12.3	52.5	46.3
89	29.9777	90.0110	<0.10	2.76	32.4	7.11	13.3	55.6	51.6
90	29.9744	90.0104	0.12	3.24	28.2	6.61	16.2	54.4	53.3
91	29.9731	90.0109	0.14	4.38	13.8	3.34	12.0	33.7	34.2
92	29.9694	90.0121	<0.10	7.57	20.0	4.61	14.3	46.5	49.8
95	29.9686	90.0197	0.10	1.51	15.5	4.89	11.5	33.5	25.0
96	29.9686	90.0197	0.14	2.59	14.11	4.11	9.14	30.1	22.3
97	29.9691	90.0211	0.81	18.5	58.0	46.4	37.7	161	141
98	29.9644	90.0260	0.16	4.26	24.6	13.9	36.3	79.2	62.2
99	29.9701	90.0229	<0.10	1.75	10.01	5.25	18.3	35.3	34.9
101	29.9699	90.0229	<0.10	4.17	20.33	3.59	15.6	43.7	35.3
102	29.9703	90.0230	<0.10	4.63	31.16	5.39	13.6	54.8	63.0
104	29.9834	89.9445	0.19	2.76	9.27	3.75	9.72	25.7	27.1
107	29.9490	89.9581	0.19	7.87	30.7	21.4	20	80.1	101
108	29.9490	89.9581	6.13	<0.10	19.7	16.1	13.7	55.6	65.0
109	29.9510	89.9491	11.2	2.78	6.21	6.08	11.1	37.5	38.6
110	29.9510	89.9491	0.25	2.15	8.45	13.5	16.9	41.2	42.3
111	29.9510	89.9491	3.36	4.27	11.87	13.6	12.5	45.6	42.9
115	29.9455	89.9565	1.14	6.78	26.1	25.6	34.6	94.2	95.1
117	29.9455	89.9565	0.21	1.84	18.5	19.5	22.4	62.4	71.4
122	29.9314	89.9459	<0.10	1.32	20.4	3.83	12.2	37.8	32.5
124	29.9336	89.9678	<0.10	2.18	26.2	5.67	13.8	47.8	85.3
127	29.9313	89.9689	<0.10	6.02	32.4	3.91	6.94	49.2	48.8
135	29.6703	89.9723	<0.10	<0.10	6.59	2.42	16.1	25.1	19.4
136	29.5004	89.7201	<0.10	0.64	12.2	2.41	15.7	30.9	35.1
138	29.4722	89.6854	0.18	22.3	118	19.2	67.4	227	249
142	29.4722	89.6854	<0.10	2.96	16.63	1.09	66.1	86.8	72.3
145	29.3883	89.6050	<0.10	1.07	3.91	0.99	10.7	16.7	18.5
150	29.3528	89.5241	0.32	0.86	16.0	4.22	6.36	27.8	42.1
151	29.3528	89.5241	0.49	1.39	13.1	4.63	10.2	29.9	29.0
152	29.3360	89.4952	<0.10	4.42	14.4	5.02	9.92	33.7	50.2
153	29.3360	89.4952	<0.10	2.27	10.1	2.9	13.5	28.7	37.4
155	29.3486	89.4625	<0.10	0.92	8.36	5.88	13.6	28.8	42.7
156	29.3486	89.4625	0.63	<0.10	7.43	6.13	17.3	31.5	36.5
157	29.2713	89.3539	<0.10	2.33	15.9	3.6	14.1	35.9	25.1

**Table 15.** Results of sequential extraction analysis for vanadium from sediment and soil collected following Hurricanes Katrina and Rita.

[mg/kg, milligram per kilogram; F1, exchangeable fraction; F2, bound to carbonate fraction; F3, iron and manganese oxides fraction; F4, organic matter fraction; F5, residual; &lt;, less than; --, not tested]

Sample number	Location		Sequential extraction fraction (mg/kg dry soil)						Single extraction (mg/kg dry soil)
	Latitude	Longitude	F1	F2	F3	F4	F5	Sum (F)	
10	30.0162	90.1981	<1.00	<1.00	7.80	2.83	50.8	61.4	54.8
14	30.0153	90.1631	<1.00	<1.00	15.1	15.7	63.3	94.0	75.5
15	30.0153	90.1631	<1.00	<1.00	5.62	8.21	30.3	44.2	55.9
16	30.0178	90.1204	<1.00	<1.00	9.67	3.02	44.6	57.3	57.8
26	30.0196	90.1073	<1.00	<1.00	8.52	2.23	57.8	68.5	60.0
29	30.0170	90.1067	<1.00	<1.00	4.26	4.41	10.6	19.3	17.0
30	30.0170	90.1067	<1.00	<1.00	9.57	8.50	58.5	76.6	88.0
31	30.0039	90.1140	<1.00	<1.00	5.09	15.2	48.8	69.1	81.5
34	30.0039	90.1140	<1.00	<1.00	9.55	11.5	55.9	77.0	83.5
36	30.0039	90.1140	<1.00	<1.00	8.78	1.21	68.1	78.0	82.5
44	30.0086	90.0665	<1.00	<1.00	7.55	2.99	56.2	66.7	52.6
65	30.0572	89.9558	<1.00	<1.00	5.95	7.35	27.1	40.4	36.5
66	30.0477	89.9620	<1.00	<1.00	17.8	2.07	59.6	79.5	82.0
74	30.0398	89.9510	<1.00	<1.00	9.89	4.70	76.0	90.6	62.9
86	29.9424	90.0967	<1.00	<1.00	8.13	7.82	40.0	56.0	48.6
87	29.9773	90.0173	<1.00	<1.00	15.1	4.09	50.3	69.5	68.2
88	29.9786	90.0169	<1.00	<1.00	17.2	4.41	45.0	66.6	63.5
89	29.9777	90.0110	<1.00	<1.00	12.8	4.38	69.2	86.4	81.2
90	29.9744	90.0104	<1.00	<1.00	12.8	2.62	52.8	68.2	67.3
91	29.9731	90.0109	<1.00	<1.00	18.3	2.84	61.5	82.7	59.3
92	29.9694	90.0121	<1.00	<1.00	14.4	3.07	44.6	62.1	64.2
95	29.9686	90.0197	<1.00	<1.00	10.1	2.30	25.2	37.7	61.8
96	29.9686	90.0197	<1.00	<1.00	11.2	4.39	110	125.97	71.3
97	29.9691	90.0211	<1.00	<1.00	2.92	5.66	16.9	25.5	23.0
98	29.9644	90.0260	<1.00	<1.00	14.5	2.59	60.6	77.7	86.0
99	29.9701	90.0229	<1.00	<1.00	12.4	2.75	63.6	78.7	76.3
101	29.9699	90.0229	<1.00	<1.00	5.48	5.61	31.1	42.1	51.8
102	29.9703	90.0230	<1.00	<1.00	3.94	2.21	12.2	18.4	25.1
104	29.9834	89.9445	<1.00	<1.00	10.8	0.89	50.0	61.7	17.2
107	29.9490	89.9581	<1.00	<1.00	8.85	2.60	14.8	26.27	57.5
108	29.9490	89.9581	<1.00	<1.00	17.4	4.60	44.4	66.4	51.1
109	29.9510	89.9491	<1.00	<1.00	24.0	0.58	87.3	112	65.3
110	29.9510	89.9491	<1.00	<1.00	12.6	0.92	68.5	82.0	91.5
111	29.9510	89.9491	<1.00	<1.00	8.61	7.32	41.0	56.9	61.9
115	29.9455	89.9565	<1.00	<1.00	7.16	2.66	26.7	36.5	56.8
117	29.9455	89.9565	<1.00	<1.00	9.99	3.43	39.25	52.7	40.5
122	29.9314	89.9459	<1.00	<1.00	17.5	2.65	32.7	52.9	74.8
124	29.9336	89.9678	<1.00	<1.00	12.5	3.39	61.3	77.2	69.4
127	29.9313	89.9689	<1.00	<1.00	13.1	4.54	21.3	39.0	75.6
135	29.6703	89.9723	<1.00	<1.00	10.7	6.80	48.8	66.3	85.2
136	29.5004	89.7201	<1.00	<1.00	10.1	3.19	51.6	64.9	76.3
138	29.4722	89.6854	<1.00	<1.00	9.10	1.95	78.4	89.4	85.1
142	29.4722	89.6854	<1.00	<1.00	5.56	9.16	45.2	59.9	58.5
145	29.3883	89.6050	<1.00	<1.00	22.2	3.28	27.9	53.4	57.3
150	29.3528	89.5241	<1.00	<1.00	13.8	5.21	57.1	76.1	88.2
151	29.3528	89.5241	<1.00	2.38	10.9	4.14	41.8	59.2	69.0
152	29.3360	89.4952	<1.00	<1.00	17.0	6.05	63.7	86.8	92.1
153	29.3360	89.4952	<1.00	<1.00	8.02	2.80	29.2	40.0	60.0
155	29.3486	89.4625	<1.00	<1.00	13.1	2.43	79.8	95.3	89.7
156	29.3486	89.4625	<1.00	<1.00	--	8.14	34.2	--	58.7
157	29.2713	89.3539	<1.00	<1.00	14.1	11.1	82.7	108	85.6

**Table 16.** Results of sequential extraction analysis for chromium from sediment and soil collected following Hurricanes Katrina and Rita.

[mg/kg, milligram per kilogram; F1, exchangeable fraction; F2, bound to carbonate fraction; F3, iron and manganese oxides fraction; F4, organic matter fraction; F5, residual; <, less than]

Sample number	Location		Sequential extraction fraction (mg/kg dry soil)						Single extraction (mg/kg dry soil)
	Latitude	Longitude	F1	F2	F3	F4	F5	Sum (F)	
10	30.0162	90.1981	<1.00	<1.00	3.20	7.85	23.8	34.8	33.4
14	30.0153	90.1631	<1.00	<1.00	11.3	20.9	33.9	66.1	50.6
15	30.0153	90.1631	<1.00	<1.00	3.51	8.41	14.4	26.3	33.4
16	30.0178	90.1204	<1.00	<1.00	3.99	6.76	22.4	33.2	30.9
26	30.0196	90.1073	<1.00	<1.00	7.98	12.8	31.4	52.2	44.9
29	30.0170	90.1067	<1.00	<1.00	1.71	8.00	9.17	18.9	17.3
30	30.0170	90.1067	<1.00	<1.00	2.55	12.0	25.3	39.9	45.2
31	30.0039	90.1140	<1.00	<1.00	0.80	9.32	23.8	33.9	40.3
34	30.0039	90.1140	<1.00	<1.00	1.52	9.78	23.6	34.9	40.9
36	30.0039	90.1140	<1.00	<1.00	3.96	7.57	32.2	43.7	46.4
44	30.0086	90.0665	<1.00	<1.00	2.55	7.49	26.8	36.8	30.1
65	30.0572	89.9558	<1.00	<1.00	1.43	6.91	14.1	22.4	19.9
66	30.0477	89.9620	<1.00	<1.00	2.49	7.57	38.8	48.9	36.6
74	30.0398	89.9510	<1.00	<1.00	4.23	7.61	30.0	41.9	43.9
86	29.9424	90.0967	<1.00	<1.00	9.80	5.94	23.6	39.3	22.7
87	29.9773	90.0173	<1.00	<1.00	3.22	8.58	23.1	34.9	33.1
88	29.9786	90.0169	<1.00	<1.00	3.17	8.84	19.7	31.7	29.0
89	29.9777	90.0110	<1.00	<1.00	6.09	8.05	34.2	48.3	45.3
90	29.9744	90.0104	<1.00	<1.00	9.79	9.25	26.0	45.1	37.9
91	29.9731	90.0109	<1.00	<1.00	3.49	5.58	30.2	39.2	28.9
92	29.9694	90.0121	<1.00	<1.00	9.01	9.61	22.2	40.8	37.1
95	29.9686	90.0197	<1.00	<1.00	5.41	7.31	16.2	28.9	35.8
96	29.9686	90.0197	<1.00	<1.00	3.73	8.64	54.7	67.0	40.6
97	29.9691	90.0211	<1.00	<1.00	1.37	7.96	11.4	20.7	18.7
98	29.9644	90.0260	<1.00	<1.00	7.95	7.73	31.8	47.5	45.9
99	29.9701	90.0229	<1.00	<1.00	3.55	7.49	29.6	40.7	38.8
101	29.9699	90.0229	<1.00	<1.00	1.60	5.12	15.7	22.4	24.7
102	29.9703	90.0230	<1.00	<1.00	0.95	2.51	7.49	10.9	12.5
104	29.9834	89.9445	<1.00	<1.00	3.49	3.34	25.7	32.5	24.9
107	29.9490	89.9581	<1.00	<1.00	4.74	3.57	8.69	17.0	30.1
108	29.9490	89.9581	<1.00	<1.00	5.25	4.61	27.8	37.7	30.7
109	29.9510	89.9491	<1.00	<1.00	4.30	4.75	41.2	50.2	31.5
110	29.9510	89.9510	<1.00	<1.00	3.06	3.75	32.3	39.1	41.7
111	29.9510	89.9491	<1.00	<1.00	2.06	5.59	19.9	27.5	25.6
115	29.9455	89.9565	<1.00	<1.00	1.93	4.75	13.4	20.0	31.0
117	29.9455	89.9565	<1.00	<1.00	6.75	5.76	22.9	35.4	38.3
122	29.9314	89.9459	<1.00	<1.00	52.4	30.6	32.9	116	81.2
124	29.9336	89.9678	<1.00	<1.00	5.12	6.80	31.7	43.6	37.2
127	29.9313	89.9689	<1.00	<1.00	3.12	4.49	10.6	18.2	42.0
135	29.6703	89.9723	<1.00	<1.00	2.04	4.91	25.0	31.9	44.8
136	29.5004	89.7201	<1.00	<1.00	1.82	4.62	25.7	32.1	46.2
138	29.4722	89.6854	<1.00	<1.00	1.88	4.1	37.8	43.7	49.1
142	29.4722	89.6854	<1.00	<1.00	1.15	6.99	23.0	31.1	31.7
145	29.3883	89.6050	<1.00	<1.00	2.39	4.96	11.7	19.1	20.9
150	29.3528	89.5241	<1.00	<1.00	2.65	8.43	26.4	37.5	43.4
151	29.3528	89.5241	<1.00	<1.00	2.18	4.85	20.1	27.1	35.7
152	29.3360	89.4952	<1.00	<1.00	2.97	4.25	32.7	40.0	46.0
153	29.3360	89.4952	<1.00	<1.00	3.42	7.7	18.9	30.0	31.0
155	29.3486	89.4625	<1.00	<1.00	3.05	5.29	37.3	45.6	44.9
156	29.3486	89.4625	<1.00	<1.00	1.60	5.88	18.1	25.5	30.9
157	29.2713	89.3539	<1.00	<1.00	1.73	11.2	35.6	48.6	39.3

**Table 17.** Results of sequential extraction analysis for copper from sediment and soil collected following Hurricanes Katrina and Rita.

[mg/kg, milligram per kilogram; F1, exchangeable fraction; F2, bound to carbonate fraction; F3, iron and manganese oxides fraction; F4, organic matter fraction; F5, residual; &lt;, less than]

Sample number	Location		Sequential extraction fraction (mg/kg dry soil)						Single extraction (mg/kg dry soil)
	Latitude	Longitude	F1	F2	F3	F4	F5	Sum (F)	
10	30.0162	90.1981	<0.40	0.99	1.68	11.8	17.7	32.2	28.1
14	30.0153	90.1631	33.7	183	60.5	716	157	1,149	960
15	30.0153	90.1631	<0.40	1.42	1.25	17	19.1	38.8	45.4
16	30.0178	90.1204	<0.40	1.94	5.90	28.4	20.1	56.3	38.2
26	30.0196	90.1073	<0.40	1.57	5.54	33.5	19.8	60.5	56.2
29	30.0170	90.1067	<0.40	1.04	2.56	37.7	14.3	55.6	51.5
30	30.0170	90.1067	<0.40	0.64	0.61	5.87	25.7	32.8	30.3
31	30.0039	90.1140	<0.40	<0.40	0.10	5.93	20.2	26.2	25.0
34	30.0039	90.1140	<0.40	<0.40	0.20	6.58	21.4	28.2	28.1
36	30.0039	90.1140	<0.40	1.66	3.03	26.6	26.3	57.6	64.5
44	30.0086	90.0665	<0.40	0.81	1.75	19.7	21.4	43.7	36.6
65	30.0572	89.9558	<0.40	0.67	0.97	8.66	16.8	27.1	23.2
66	30.0477	89.9620	<0.40	<0.40	1.24	11.5	23.0	35.8	32.9
74	30.0398	89.9510	<0.40	0.97	4.30	11.1	18.3	34.6	33.5
86	29.9424	90.0967	<0.40	1.11	1.93	11.2	19.8	34.1	28.9
87	29.9773	90.0173	<0.40	0.49	1.4	8.68	15.75	26.3	22.6
88	29.9786	90.0169	<0.40	0.76	1.72	7.38	15.0	24.8	23.8
89	29.9777	90.0110	<0.40	1.13	3.16	14.2	26.2	44.7	40.2
90	29.9744	90.0104	<0.40	<0.40	1.83	17.3	18.3	37.5	36.3
91	29.9731	90.0109	<0.40	1.79	3.41	12.3	20.0	37.5	30.3
92	29.9694	90.0121	<0.40	<0.40	5.22	9.91	16.9	32.1	34.0
95	29.9686	90.0197	<0.40	<0.40	2.23	11.3	15.6	29.1	28.6
96	29.9686	90.0197	<0.40	0.92	2.51	25.2	33.7	62.3	47.1
97	29.9691	90.0211	<0.40	<0.40	0.88	7.56	13.1	21.5	20.6
98	29.9644	90.0260	<0.40	<0.40	2.99	13.4	20.0	36.4	35.8
99	29.9701	90.0229	<0.40	0.48	1.41	11.1	20.1	33.1	32.6
101	29.9699	90.0229	<0.40	0.54	2.33	6.89	16.9	26.7	28.1
102	29.9703	90.0230	<0.40	<0.40	1.00	1.02	6.48	8.50	11.4
104	29.9834	89.9445	<0.40	1.57	8.90	4.34	14.7	29.5	12.2
107	29.9490	89.9581	<0.40	1.77	3.38	6.51	6.41	18.1	24.4
108	29.9490	89.9581	<0.40	0.66	4.53	6.43	14.6	26.2	21.6
109	29.9510	89.9491	<0.40	<0.40	2.94	6.94	18.0	27.9	21.4
110	29.9510	89.9491	<0.40	<0.40	2.74	5.18	17.9	25.8	23.8
111	29.9510	89.9491	<0.40	0.63	1.11	3.05	14.0	18.8	19.7
115	29.9455	89.9565	<0.40	<0.40	0.5	1.31	8.97	10.8	18.8
117	29.9455	89.9565	<0.40	3.66	19.0	18.4	22.4	63.5	53.2
122	29.9314	89.9459	<0.40	11.7	17.2	75.1	35.0	139	125
124	29.9336	89.9678	<0.40	1.17	1.14	14.1	21.1	37.5	28.4
127	29.9313	89.9689	<0.40	0.64	4.11	6.23	9.42	20.4	32.0
135	29.6703	89.9723	<0.40	0.42	1.91	4.46	17.8	24.5	26.7
136	29.5004	89.7201	<0.40	<0.40	1.51	4.1	14.2	19.8	30.1
138	29.4722	89.6854	<0.40	<0.40	2.29	6.13	19.0	27.4	30.6
142	29.4722	89.6854	<0.40	0.47	0.98	3.23	26.2	30.9	33.5
145	29.3883	89.6050	<0.40	0.66	1.46	3.96	7.32	13.4	15.7
150	29.3528	89.5241	<0.40	0.69	1.42	7.06	18.1	27.3	26.9
151	29.3528	89.5241	<0.40	<0.40	1.74	9.13	18.2	29.1	25.9
152	29.3360	89.4952	<0.40	0.55	1.71	3.19	20.7	26.1	31.4
153	29.3360	89.4952	<0.40	1.42	13.0	43.9	36.4	94.7	85.5
155	29.3486	89.4625	<0.40	0.95	4.98	10.0	30.0	46	41.2
156	29.3486	89.4625	<0.40	<0.40	1.3	4.31	13.7	19.3	23.0
157	29.2713	89.3539	<0.40	<0.40	0.66	7.91	29.7	38.2	39.8



**Table 18.** Results of sequential extraction analysis for arsenic from sediment and soil collected following Hurricanes Katrina and Rita.

[mg/kg, miligram per kilogram; F1, exchangeable fraction; F2, bound to carbonate fraction; F3, iron and manganese oxides fraction; F4, organic matter fraction; F5, residual; <MDL, less than method detection limit; <, less than]

Sample number	Location		Sequential extraction fraction (mg/kg dry soil)						Single extraction (mg/kg dry soil)
	Latitude	Longitude	F1	F2	F3	F4	F5	Sum (F)	
10	30.0162	90.1981	<0.10	0.23	6.73	0.51	5.40	12.9	8.16
14	30.0153	90.1631	<0.10	0.74	16.6	2.78	7.79	27.9	14.6
15	30.0153	90.1631	<0.10	0.40	3.54	1.62	2.33	7.88	8.13
16	30.0178	90.1204	<0.10	0.42	13.3	0.59	5.40	19.7	11.7
26	30.0196	90.1073	<0.10	0.27	4.69	0.66	7.52	13.1	10.5
29	30.0170	90.1067	<0.10	0.34	2.66	0.37	2.39	5.76	4.18
30	30.0170	90.1067	<0.10	<0.10	20.0	3.68	5.21	28.9	15.0
31	30.0039	90.1140	<0.10	0.33	5.95	4.11	3.00	13.4	9.34
34	30.0039	90.1140	<0.10	0.25	9.71	2.90	2.86	15.7	8.76
36	30.0039	90.1140	<0.10	0.49	14.5	0.79	11.9	27.7	23.1
44	30.0086	90.0665	<0.10	0.27	7.15	0.92	8.30	16.6	12.5
65	30.0572	89.9558	<0.10	0.83	17.6	2.56	6.41	27.4	13.5
66	30.0477	89.9620	<0.10	0.54	9.59	0.34	7.95	18.4	11.5
74	30.0398	89.9510	<0.10	0.27	6.22	1.23	7.51	15.2	11.1
86	29.9424	90.0967	<0.10	1.22	10.2	0.54	6.72	18.7	12.4
87	29.9773	90.0173	<0.10	0.21	10.7	1.20	4.23	16.3	9.11
88	29.9786	90.0169	<0.10	0.46	10.2	1.12	3.14	14.9	7.01
89	29.9777	90.0110	<0.10	0.15	14.4	0.91	5.62	21.1	12.1
90	29.9744	90.0104	<0.10	0.42	13.0	1.05	3.88	18.4	11.1
91	29.9731	90.0109	<0.10	0.21	5.64	0.36	8.65	14.9	11.4
92	29.9694	90.0121	<0.10	0.75	8.35	<0.10	3.93	13.0	9.65
95	29.9686	90.0197	<0.10	0.52	7.81	0.52	3.41	12.3	8.20
96	29.9686	90.0197	<0.10	0.23	5.69	1.17	10.5	17.6	11.3
97	29.9691	90.0211	<0.10	1.63	26.8	10.2	13.5	52.2	33.8
98	29.9644	90.0260	<0.10	1.15	12.18	1.09	4.49	18.9	12.2
99	29.9701	90.0229	<0.10	0.37	9.19	0.96	5.36	15.9	11.3
101	29.9699	90.0229	<0.10	0.93	28.0	2.79	15.4	47.1	27.9
102	29.9703	90.0230	<0.10	1.06	28.3	3.9	5.84	39.1	25.2
104	29.9834	89.9445	<0.10	0.29	12.0	0.23	13.4	25.9	20.7
107	29.9490	89.9581	<0.10	1.24	35.3	0.93	13.3	50.7	16.4
108	29.9490	89.9581	<0.10	0.56	15.2	0.82	16.6	33.2	21.2
109	29.9510	89.9491	<0.10	<0.10	4.72	<0.10	10.7	15.4	11.3
110	29.9510	89.9491	<0.10	0.16	5.43	<MDL	6.48	12.1	11.2
111	29.9510	89.9491	<0.10	0.19	2.96	0.33	3.47	6.96	6.65
115	29.9455	89.9565	<0.10	<0.10	6.93	0.41	3.54	10.9	11.8
117	29.9455	89.9565	<0.10	2.35	39.7	1.15	30.3	73.5	49.1
122	29.9314	89.9459	<0.10	0.42	16.9	0.54	22.2	40.1	27.0
124	29.9336	89.9678	<0.10	0.62	19.2	1.03	8.01	28.9	15.3
127	29.9313	89.9689	<0.10	<0.10	7.75	0.37	3.48	11.6	14.5
135	29.6703	89.9723	<0.10	0.13	3.54	0.79	3.71	8.17	13.0
136	29.5004	89.7201	<0.10	0.13	2.61	0.17	5.95	8.86	8.8
138	29.4722	89.6854	<0.10	<0.10	2.05	<0.10	6.63	8.67	9.33
142	29.4722	89.6854	<0.10	0.17	2.78	0.99	2.91	6.85	4.92
145	29.3883	89.6050	<0.10	0.41	11.8	0.5	15.1	27.8	22.8
150	29.3528	89.5241	<0.10	0.31	7.41	1.65	4.67	14.0	11.7
151	29.3528	89.5241	<0.10	0.37	4.59	0.21	1.87	7.04	7.67
152	29.3360	89.4952	<0.10	0.17	3.49	<0.10	4.73	8.38	8.15
153	29.3360	89.4952	<0.10	0.21	4.39	0.1	8.76	13.5	15.8
155	29.3486	89.4625	<0.10	<0.10	6.15	0.34	8.48	15.0	10.5
156	29.3486	89.4625	<0.10	0.16	2.17	0.77	3.28	6.38	7.1
157	29.2713	89.3539	<0.10	<0.10	9.31	3.29	3.21	15.8	14.1

**Table 19.** Results of sequential extraction analysis for cadmium from sediment and soil following Hurricanes Katrina and Rita.

[mg/kg, miligram per kilogram; F1, exchangeable fraction; F2, bound to carbonate fraction; F3, iron and manganese oxides fraction; F4, organic matter fraction; F5, residual; <MDL, less than method detection limit; <, less than; --, not tested]

Sample number	Location		Sequential extraction fraction (mg/kg dry soil)						Single extraction (mg/kg dry soil)
	Latitude	Longitude	F1	F2	F3	F4	F5	Sum (F)	
10	30.0162	90.1981	0.28	0.16	0.25	0.02	0.02	0.73	0.48
14	30.0153	90.1631	1.02	<0.01	0.09	0.02	0.04	1.17	1.17
15	30.0153	90.1631	0.30	0.30	0.45	0.09	0.04	1.18	1.36
16	30.0178	90.1204	0.19	0.21	0.39	0.02	0.02	0.83	0.93
26	30.0196	90.1073	0.64	0.23	0.44	0.07	0.05	1.44	1.09
29	30.0170	90.1067	0.48	0.26	0.74	0.10	0.14	1.73	2.01
30	30.0170	90.1067	0.65	<0.01	0.05	0.01	<0.01	0.71	0.92
31	30.0039	90.1140	<MDL	<0.01	0.18	0.03	0.02	0.23	0.37
34	30.0039	90.1140	0.20	<0.01	0.33	0.04	<0.01	0.57	0.56
36	30.0039	90.1140	0.67	0.60	1.30	0.11	0.04	2.72	2.05
44	30.0086	90.0665	<0.01	<0.01	0.72	0.07	0.03	0.83	0.65
65	30.0572	89.9558	0.24	<0.01	0.17	0.03	<0.01	0.43	0.36
66	30.0477	89.9620	0.22	<0.01	0.32	0.05	0.04	0.64	0.61
74	30.0398	89.9510	<0.01	0.24	0.30	0.03	0.03	0.59	0.67
86	29.9424	90.0967	0.30	<0.01	0.18	0.02	0.04	0.55	0.51
87	29.9773	90.0173	0.34	<0.01	0.20	0.02	0.02	0.58	0.45
88	29.9786	90.0169	0.19	0.17	0.17	0.04	0.07	0.64	0.32
89	29.9777	90.0110	0.15	0.31	0.88	0.07	0.04	1.46	1.62
90	29.9744	90.0104	<0.01	<0.01	1.01	0.33	0.03	1.37	1.47
91	29.9731	90.0109	0.36	0.16	0.14	0.03	0.04	0.73	0.58
92	29.9694	90.0121	<0.01	<0.01	0.55	0.11	0.04	0.70	0.79
95	29.9686	90.0197	<0.01	<0.01	0.66	0.08	0.02	0.76	0.76
96	29.9686	90.0197	0.41	<0.01	0.41	0.09	0.06	0.97	0.81
97	29.9691	90.0211	0.31	<0.01	0.07	0.02	<0.01	0.41	0.45
98	29.9644	90.0260	<0.01	<0.01	0.85	0.06	0.03	0.95	0.84
99	29.9701	90.0229	<0.01	0.20	0.42	0.05	0.03	0.71	0.63
101	29.9699	90.0229	0.20	<0.01	0.16	0.01	<0.01	0.37	0.45
102	29.9703	90.0230	0.25	<0.01	0.07	<0.01	<0.01	0.32	0.36
104	29.9834	89.9445	<0.01	<0.01	0.14	0.01	0.04	0.19	0.26
107	29.9490	89.9581	<0.01	<0.01	0.08	0.02	<0.01	0.10	0.42
108	29.9490	89.9581	0.29	<0.01	0.27	0.02	0.09	0.66	0.63
109	29.9510	89.9491	0.20	<0.01	0.12	0.13	0.05	0.49	0.29
110	29.9510	89.9491	<0.01	<0.01	0.12	0.01	0.03	0.16	0.32
111	29.9510	89.9491	<0.01	<0.01	0.07	0.01	0.03	0.11	0.22
115	29.9455	89.9565	0.21	<0.01	0.08	0.01	<0.01	0.30	0.26
117	29.9455	89.9565	0.33	0.18	0.33	0.02	0.03	0.90	0.69
122	29.9314	89.9459	1.79	3.00	2.39	0.14	0.10	7.42	4.30
124	29.9336	89.9678	<0.01	0.26	1.00	0.06	0.03	1.34	1.32
127	29.9313	89.9689	0.27	<0.01	0.19	0.02	<0.01	0.47	0.76
135	29.6703	89.9723	0.18	0.58	0.17	0.01	0.05	0.99	0.53
136	29.5004	89.7201	0.25	<0.01	0.21	0.03	0.03	0.53	0.59
138	29.4722	89.6854	0.28	<0.01	0.25	0.04	0.04	0.61	0.74
142	29.4722	89.6854	0.27	<0.01	0.24	0.03	0.03	0.57	0.65
145	29.3883	89.6050	<0.01	<0.01	0.08	--	<0.01	--	0.35
150	29.3528	89.5241	<0.01	<0.01	0.17	0.02	0.03	0.23	0.42
151	29.3528	89.5241	<0.01	<0.01	0.38	0.04	0.05	0.47	0.54
152	29.3360	89.4952	<0.01	0.15	0.21	0.03	0.05	0.43	0.75
153	29.3360	89.4952	0.86	0.39	1.19	0.13	0.12	2.7	1.48
155	29.3486	89.4625	0.20	<0.01	0.18	0.02	0.05	0.45	0.48
156	29.3486	89.4625	0.31	0.17	0.23	0.03	0.03	0.75	0.59
157	29.2713	89.3539	0.30	<0.01	0.27	0.03	0.06	0.66	1.12

**Table 20.** Results of sequential extraction analysis for iron from sediment and soil collected following Hurricanes Katrina and Rita.

[mg/kg, milligram per kilogram; F1, exchangeable fraction; F2, bound to carbonate fraction; F3, iron and manganese oxides fraction; F4, organic matter fraction; F5, residual; <, less than]

Sample number	Location		Sequential extraction fraction (mg/kg dry soil)					Sum (F)	Single extraction (mg/kg dry soil)
	Latitude	Longitude	F1	F2	F3	F4	F5		
10	30.0162	90.1981	<15.0	74.0	6,560	3,260	17,300	27,200	22,400
14	30.0153	90.1631	<15.0	17.0	2,340	2,700	18,600	23,600	22,700
15	30.0153	90.1631	<15.0	<15.0	1,670	2,020	11,500	15,200	17,200
16	30.0178	90.1204	<15.0	241	7,810	2,060	16,100	261,200	21,000
26	30.0196	90.1073	<15.0	33.0	2,370	4,570	15,200	22,200	22,800
29	30.0170	90.1067	<15.0	<15.0	282	607	7,650	8,540	9,490
30	30.0170	90.1067	<15.0	897	6,080	4,880	15,800	27,600	26,200
31	30.0039	90.1140	<15.0	<15.0	2,590	8,860	12,300	23,700	24,100
34	30.0039	90.1140	<15.0	121	4,100	7,600	13,200	25,000	23,700
36	30.0039	90.1140	<15.0	106	5,590	4,340	19,100	29,200	37,200
44	30.0086	90.0665	<15.0	36.0	4,480	4,750	19,800	29,000	24,000
65	30.0572	89.9558	<15.0	<15.0	3,150	1,870	9,570	14,600	13,700
66	30.0477	89.9620	<15.0	228	7,160	1,120	17,800	26,300	22,400
74	30.0398	89.9510	<15.0	77.0	4,870	5,910	24,100	34,900	27,200
86	29.9424	90.0967	<15.0	42.0	3,050	1,540	14,100	18,700	17,700
87	29.9773	90.0173	<15.0	242	8,690	4,660	22,300	35,900	33,600
88	29.9786	90.0169	<15.0	432	9,890	4,050	19,500	33,900	30,800
89	29.9777	90.0110	<15.0	192	10,800	2,470	18,000	31,500	30,900
90	29.9744	90.0104	<15.0	1,440	6,920	3,420	14,600	26,400	22,300
91	29.9731	90.0109	<15.0	68.0	4,680	1,880	18,100	24,800	18,100
92	29.9694	90.0121	<15.0	1,750	5,100	952	16,300	24,100	20,000
95	29.9686	90.0197	<15.0	691	5,590	2,090	12,400	20,800	19,100
96	29.9686	90.0197	<15.0	59.0	6,820	5,860	31,500	44,300	11,200
97	29.9691	90.0211	<15.0	28.0	1,470	1,490	5,490	8,470	9,400
98	29.9644	90.0260	<15.0	1,090	12,100	3,920	17,900	35,000	26,900
99	29.9701	90.0229	<15.0	251	8,320	4,840	16,900	30,300	26,300
101	29.9699	90.0229	<15.0	111	3,320	837	10,600	14,900	15,100
102	29.9703	90.0230	<15.0	127	2,520	462	4,130	7,240	7,800
104	29.9834	89.9445	<15.0	<15.0	3,780	233	18,000	22,100	8,400
107	29.9490	89.9581	<15.0	<15.0	2,140	197	5,650	7,990	22,200
108	29.9490	89.9581	<15.0	<15.0	4,300	220	15,700	20,200	20,000
109	29.9510	89.9491	<15.0	<15.0	8,100	1,850	31,400	41,300	27,100
110	29.9510	89.9491	<15.0	24.0	4,190	993	19,800	25,000	26,500
111	29.9510	89.9491	<15.0	72.0	4,050	1,200	14,500	19,800	16,600
115	29.9455	89.9565	<15.0	<15.0	4,000	1,220	12,200	17,400	13,900
117	29.9455	89.9565	<15.0	<15.0	23,780	200	12,800	15,400	17,300
122	29.9314	89.9459	<15.0	295	20,600	1,520	31,900	54,300	56,200
124	29.9336	89.9678	<15.0	95.0	6,160	2,630	16,800	25,700	28,300
127	29.9313	89.9689	<15.0	<15.0	5,090	859	18,300	24,300	24,800
135	29.6703	89.9723	<15.0	<15.0	4,000	5,480	14,200	23,700	26,200
136	29.5004	89.7201	<15.0	22.0	3,370	1,880	24,500	29,800	23,700
138	29.4722	89.6854	<15.0	<15.0	4,460	1,310	23,400	29,200	27,000
142	29.4722	89.6854	<15.0	<15.0	2,750	1,730	13,800	18,300	17,400
145	29.3883	89.6050	<15.0	1,136	15,000	3,180	15,800	35,100	35,100
150	29.3528	89.5241	<15.0	134	6,250	4,660	14,700	25,700	27,400
151	29.3528	89.5241	<15.0	1,140	3,920	967	15,300	21,300	16,900
152	29.3360	89.4952	<15.0	68.0	4,750	615	18,900	24,400	20,500
153	29.3360	89.4952	<15.0	<15.0	5,360	1,330	24,500	31,200	27,800
155	29.3486	89.4625	<15.0	<15.0	4,940	1,180	24,900	31,000	30,400
156	29.3486	89.4625	<15.0	<15.0	2,190	962	16,900	20,100	17,400
157	29.2713	89.3539	<15.0	177	6,110	6,550	15,600	28,500	25,600







**Table 21.** Results of pesticides and polychlorinated biphenyl arochlors measured by Gas Chromatograph-Electron Capture Detection from sediment and soil collected following Hurricanes Katrina and Rita.—Continued

[µg/kg, microgram per kilogram; <, less than; ND, no detection]

Sample number	Location		Pesticide (µg/kg dry weight)					Polychlorinated biphenyl arochlors congeners (µg/kg)									
	Latitude	Longitude	Simazine	Atrazine	Hep-tachlor	Methoxy-chlor	1016	1221	1232	1242	1248	1254	1260	1248	1254	1260	
91	29.9731	90.0109	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
92	29.9694	90.0121	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
93	29.9686	90.0197	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
94	29.9686	90.0197	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
95	29.9686	90.0197	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
96	29.9686	90.0197	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
97	29.9691	90.0211	<11.8	<9.40	<0.40	<0.40	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<3.60	<3.60	
98	29.9644	90.0260	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
99	29.9701	90.0229	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
100	29.9701	90.0229	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
101	29.9699	90.0229	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
102	29.9703	90.0230	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
103	29.9834	89.9445	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
104	29.9834	89.9445	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
105	29.9834	89.9445	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
106	29.9490	89.9581	<11.8	<9.40	<0.40	<0.40	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<3.60	<3.60	
107	29.9490	89.9581	<11.8	<9.40	<0.40	<0.40	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<3.60	<3.60	
108	29.9490	89.9581	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
109	29.9510	89.9491	<11.8	<9.40	<0.40	<0.40	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<3.60	<3.60	
110	29.9510	89.9491	<11.8	<9.40	<0.40	<0.40	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<3.60	<3.60	
111	29.9510	89.9491	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
112	29.9474	89.9446	<11.8	<9.40	<0.40	<0.40	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<3.60	<3.60	
113	29.9474	89.9446	<11.8	<9.40	<0.40	<0.40	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<3.60	<3.60	
114	29.9474	89.9446	<11.8	<9.40	<0.40	<0.40	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<3.60	<3.60	
115	29.9455	89.9565	<11.8	<9.40	<0.40	<0.40	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<3.60	<3.60	
116	29.9455	89.9565	<11.8	<9.40	<0.40	<0.40	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<3.60	<3.60	
117	29.9455	89.9565	<11.8	<9.40	<0.40	<0.40	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<3.60	<3.60	
118	29.9438	89.9257	<11.8	<9.40	<0.40	<0.40	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<3.60	<3.60	
119	29.9438	89.9257	<11.8	<9.40	<0.40	<0.40	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<3.60	<3.60	
120	29.9438	89.9257	<11.8	<9.40	<0.40	<0.40	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<7.90	<3.60	<3.60	







**Table 22.** Results of pesticide compounds measured by Gas Chromatograph-Mass Spectrometry from sediment and soil collected following Hurricanes Katrina and Rita.

[µg/kg, microgram per kilogram]

Sample number	Location		Concentration (µg/kg dry soil)				
	Latitude	Longitude	Prometon	Simazine	Atrazine	Heptachlor	Methoxychlor
12	30.0162	90.1981	0.67	0.44	4.76	0.44	36.2
13	30.0153	90.1631	0.67	0.44	0.27	2.88	68.5
14	30.0153	90.1631	7.37	0.44	49.7	0.44	2,040
21	30.0178	90.1204	106	0.44	0.27	0.44	3.47
31	30.0039	90.1140	0.67	0.44	6.45	0.44	3.47
34	30.0039	90.1140	7.50	0.44	0.27	0.44	439
39	30.0122	90.0692	0.67	0.44	10.1	0.44	3.47
40	30.0107	90.0687	11.8	10.5	0.27	0.44	3.47
41	30.0100	90.0673	36.2	0.44	9.53	0.44	3.47
43	30.0095	90.0687	5.71	0.44	4.45	0.44	3.47
44	30.0086	90.0665	44.3	0.44	8.00	0.44	3.47
45	30.0086	90.0665	0.67	0.44	14.4	0.44	3.47
49	30.0256	90.0231	0.67	0.44	0.27	0.44	3.47
52	30.0256	90.0231	0.67	0.44	0.27	0.44	3.47
65	30.0572	89.9558	0.67	0.44	25.1	0.44	3.47
85	29.9412	90.1034	0.67	0.44	5.41	0.44	190
87	29.9773	90.0173	10.5	0.44	0.27	0.44	143
88	29.9786	90.0169	9.03	0.44	0.27	22.2	330
89	29.9777	90.0110	14.2	0.44	0.27	0.44	3.47
90	29.9744	90.0104	35.7	82.4	0.27	0.44	3.47
91	29.9731	90.0109	21.0	45.3	25.0	0.44	3.47
92	29.9694	90.0121	4.60	0.44	0.27	0.44	3.55
93	29.9686	90.0197	6.66	0.44	0.27	0.44	3.47
94	29.9686	90.0197	0.67	0.44	0.27	0.44	3.47
96	29.9686	90.0197	9.67	0.44	0.27	0.44	163
98	29.9644	90.0260	7.30	0.44	0.27	33.3	463
99	29.9701	90.0229	10.3	0.44	0.27	0.44	3.47
100	29.9701	90.0229	0.67	0.44	0.27	0.44	59.6
101	29.9699	90.0229	6.18	0.44	0.27	0.44	3.47
102	29.9703	90.0230	0.67	0.44	0.27	0.44	115
104	29.9834	89.9445	193	0.44	187	0.44	3.47
105	29.9834	89.9445	7.44	0.44	7.14	0.44	35.7
108	29.9490	89.9581	0.34	0.44	10.5	0.44	3.47
111	29.9510	89.9491	15.7	0.44	0.27	0.44	35.7
123	29.9314	89.9459	2.37	0.44	8.88	6.31	3.47
139	29.4722	89.6854	9.10	6.95	0.27	12.4	3,510
141	29.4722	89.6854	0.34	4.79	0.27	3.70	357
142	29.4722	89.6854	26.3	21.4	8.74	4.96	332
143	29.4722	89.6854	27.2	27.7	0.27	0.44	3.47
152	29.3360	89.4952	10.2	0.44	11.1	0.44	3.47
153	29.3360	89.4952	0.67	0.44	6.66	0.44	57.6
157	29.2713	89.3539	0.67	0.44	21.9	0.44	3.47







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