Recurrent sampling in soils inundated by Hurricane Katrina, St. Bernard Parish, Louisiana: Analytical results

Douglas E. Wyatt and Michele Harmon

ABSTRACT

Recent flooding in New Orleans as a result of Hurricane Katrina caused surface waters to mingle with a variety of hazardous chemicals. The prolonged inundation of low-lying neighborhoods caused the potentially contaminated surface waters to saturate the underlying soils, possibly leaving behind contaminants once the floodwater receded. An area of Chalmette, St. Bernard Parish, was sampled on three occasions for the presence of Resource Conservation and Recovery Act (RCRA) metals and volatile organic carbons. Seven sample sites were established and sampled to a depth of 2 m (6.6 ft) on two or three site visits separated by approximately 30 days each. Additionally, surface bag sediments from each site were collected for toxicity testing. A total of 78 soil core, 12 surface soil bag, and several field reference samples were acquired.

Key research questions were as follows. (1) Are detectable flood-related contaminants present in soil samples? (2) Are contaminants present at varying depths? (3) Do the concentrations of analytes change over time and by depth? (4) Are there possible toxicity and bioaccumulation effects?

Flood-deposited sediments contained detectable contaminants. Sediment analysis revealed detectable levels of metals and organics in the soil at each location at each depth sampled. With deeper depths sampled, metal concentrations generally remained consistent, whereas the volatile organic concentrations generally decreased. Trending change in concentrations between events indicates a depth effect for metals. Results for volatile organics were mixed. Potential toxicity and bioaccumulation results will be discussed in the future.

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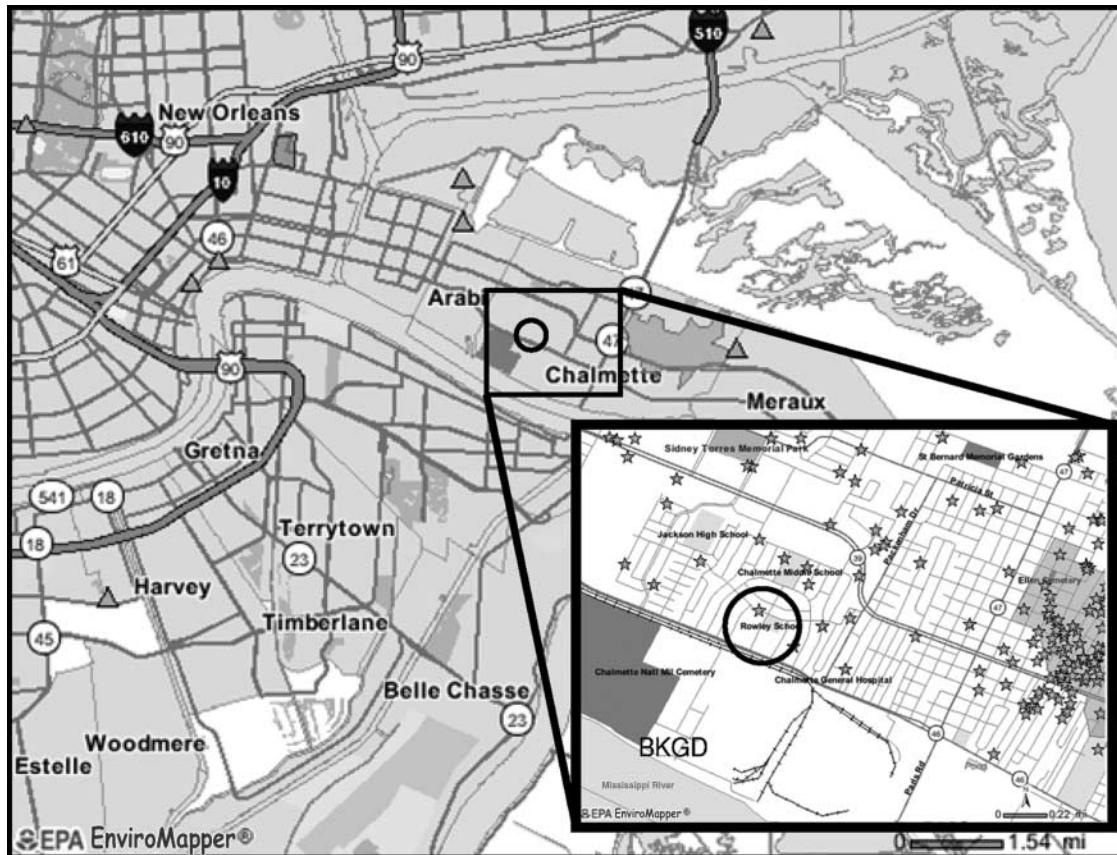
Figure 1. The study area in St. Bernard Parish, Louisiana. The stars on the inset figure represent local USEPA sampling locations most associated with the Murphy oil spill east of the study location. Sampling locations are within the circled area. The neighborhood where the study occurred was locally known as Chalmette Vista. The study area met the research criteria of being near a school, playground, local housing, public use areas, and adjacent to industrial facilities. Figures are from the USEPA. Some sample locations are also found on LDEQ maps (LDEQ, 2006b).

INTRODUCTION

Recent flooding in the greater New Orleans area associated with storm surge and levy breaches caused by Hurricane Katrina, a category 3 hurricane (Knabb et al., 2005), followed by inundation of low-lying areas, allowed large volumes of flood water to come into contact with hazardous surface chemicals. The flooding in St. Bernard Parish began on the morning of August 29 as a result of a massive storm surge channeled into Lake Borgne and transferred into the Mississippi River Gulf outlet (MRGO), damaging and overflowing the levees. Concurrently, parts of St. Bernard Parish, as well as the adjacent lower Ninth Ward of Orleans Parish, were flooded when the eastern levy of the Industrial Canal failed (Nelson, 2006). Overall flooding continued until equalization with lake waters approximately midday of September 1, 2005. The study area remained flooded for approximately 14 days, with decreasing water lev-

els and was drained by September 16, 2005 (LDEQ, 2006a).

The study area located in Chalmette, Saint Bernard Parish (Figure 1), has an average elevation of approximately mean sea level to 1.5 m (5 ft) below sea level. Water marks on the buildings in the study area verified local comments that the water was approximately 3.5 m (11 ft) deep at maximum flooding (C. Colomb, 2005, personal communication). The Federal Emergency Management Agency (FEMA) recorded maximum flood-water mark depths at 10.7 ft (3.2 m) at a measurement site (KLAC-07-67) immediately adjacent to the study area (FEMA, 2006). The potential that flood waters were fully saturating the thin soil column or vadose zone was verified by the observation of drainage through the soils to an existing drainage ditch that intersected the water table. Groundwater elevation was maintained by a series of canals and pump stations and was approximately 1 m (3.3 ft) below land surface during this study as

determined by sample coring (indicating fully saturated sediments at depth). The drainage canal that transected the area maintained a fluid level at approximately 1 m (3.3 ft) below the surface, and water was observed to be actively seeping from the surrounding soils into the canal. During the first visit, surface soils were damp, and several shallow depressions were flooded, possibly from a recent water-line break (C. Colomb, 2005, personal communication).

Rainfall in the area post-Katrina and post-Rita was varied. For all of October 2005, the rainfall in Chalmette was 0.04 in. (0.1 cm). The rainfall in November was 0.75 in. (1.9 cm), most of which occurred on November 25 and 26 after our second sampling event. December rainfall was much higher at 3.32 in. (8.4 cm), most of which occurred the week before the third sampling trip. During the second and third sampling visit, the shallow depressions were dry, and the groundwater elevation as observed in the drainage ditch was approximately 10–15 cm (3.9–5.9 in.) lower than the first visit. Sampling began 45 days post-Katrina flooding and approximately 26 days after the rainfall effects of Hurricane Rita on September 23–25, 2005 (approximately 10 cm [4 in.] of rainfall in the study area).

The only flood deposit noticed within the study area was a layer of gray, fine-grained silty sediment 2–4 cm (0.8–1.5 in.) thick. All exposed flat-lying areas were covered by this sediment to varying degrees as were surfaces in buildings, on cars, and on vegetation. Deposits from levy breach splays (i.e., Nelson and Leclair, 2006) or other deposition from swift-moving waters were not observed.

Contaminants known or anticipated to be on the water include petroleum products and distillates, insecticides, herbicides, industrial waste byproducts, human and animal sewage, pharmaceuticals, heavy metals, etc. (numerous U.S. Environmental Protection Agency [USEPA] sources). Television news reports from observers in the area described the contaminated water as a "toxic ooze," "septic tank," and "industrial sludge." An open letter from the National Council for Occupational Safety and Health (September 30, 2005) states that "The flood waters have been contaminated by 6.7 million gallons of petroleum…. The flood waters contain elevated levels of sewage, bacteria, lead, mercury, hexavalent chromium, arsenic, and pesticides…. The flood waters impacted 31 hazardous waste sites and 446 industrial facilities…." Near our study area, it was reported that "In Chalmette, at C.F. Rowley Middle School's playground, for example, analysis found benzo(a)pyrene, a toxic petroleum-based product, in levels 33 times

higher than the EPA recommendation for a residential area", (Torres, 2005).

However, subsequent reports by state and federal agencies confirmed localized contamination, but denied regionalized contamination. The Louisiana Department of Environmental Quality (LDEQ) issued a statement in August 2006 stating that "There was no toxic gumbo after the storm, and there was no toxic sediment… We have sampling results, and state and federal scientists agree that there were some localized areas that contained elevated levels of some pollutants. However, it is safe to say that environmentally, New Orleans is back to its pre-Katrina levels" (LDEQ, 2006c).

The Katrina-related Murphy oil spill occurred approximately 1000 m (3300 ft) east of our study area, with the nearest spill-related sampling typically 400–500 m (1300–1500 ft) from our sample area.

RESEARCH OBJECTIVES

Following Katrina flooding, numerous researchers sampled for hazardous substances. These included the USEPA, LDEQ, local environmental activist groups, and university researchers. Generally, sampling was conducted for floodwater, flood sediments, or surface soils. Thousands of samples were collected mostly in Orleans Parish (greater New Orleans). However, no research was conducted for deeper sediments potentially affected by the floodwater. Both surface and deeper soil contamination from hurricane-related flooding may be possible for the coastline of the southeastern United States. This effort evaluated not only surface samples, but also sampled soils at depth for potential flood-related contamination. The specific objectives of this article are as follows:

- sample potentially contaminated previously flooded near-surface sediments and establish the presence or absence of volatile organic and heavy-metal contaminants
- at areas where there is a likely probability of human-soil interaction (i.e., school yard, playground, apartments, homes), provide an initial depth-discrete distribution of contaminants within the upper 2 m (6.6 ft) of soils
- resample these test areas at approximate intervals of 30 and 60 days and compare results and establish whether contaminant concentrations are changing
- if contamination is present, evaluate the potential for toxicity and bioaccumulation

PREVIOUS WORK

This study follows previously published work by Mielke et al. (2005), Pardue et al. (2005), Cobb et al. (2006), Esworthy et al. (2006), Presley et al. (2006), and Reible et al. (2006). Most of these studies concentrate on Orleans Parish surface samples with some overlap into other areas and collected data that immediately precedes or is concurrent with data collected for this study. Although analytical suites and research approaches varied in these studies, contaminant concerns were similar to those found by this work.

Pardue et al. (2005), looking at floodwaters, found elevated levels of benzene, toluene, ethylbenzene, and xylenes (BTEX) and the metals lead ($m = 3.2$ µg/L for the Lakeview district and $m = 28$ µg/L for the Mid-City district, nearest our study area) and arsenic ($m = 30$ µg/L for Lakeview, and $m = 50.4$ for Mid-City). Cobb et al. (2006) also found arsenic and lead in soils and flood sediments above USEPA soil screening criteria. Mielke et al. (2005) compared studies made in 1992 and 2000 for metals in New Orleans soils and compared measured values with soil standards. Mielke further compared analytical values for the metals by comparing with newly deposited soils from the Mississippi River alluvium. He found that metals in outlying New Orleans areas had minimally decreased, whereas metals in the inner city had markedly increased. Presley et al. (2006) looked at flood sediments and the upper 5 cm (2 in.) of soil and found elevated values for arsenic and lead in several samples. They also detected iron in elevated concentrations.

Reible et al. (2006), summarizing results, noted that arsenic, iron, and lead were metals of concern, and that polycyclic aromatic hydrocarbons (PAHs) were of concern in postflooding soil and sediment. Reible also notes that several constituents, including arsenic, lead, several PAHs including benzo(a)pyrene, and diesel-range organics were found to exceed the LDEQ Risk Evaluation/Corrective Action Program (RECAP) (LDEQ, 2003) levels. This study did not analyze for PAHs or for semivolatile compounds. The Louisiana Bucket Brigade (Torres, 2005) reported elevated levels of numerous toxic chemicals and metals and found high levels of benzo(a)pyrene (a semivolatile) within our study area. The National Research and Development Center (NRDC, 2006, 1p.), interpreting work from others, reports that arsenic was a major contaminant of concern, averaging 12.2 µg/kg in soil in Orleans Parish, with the highest concentrations in Uptown and Carrollton (''nearly 20 mg/kg'') and the lowest in Gentilly in St. Bernard Parish (''slightly over 4 mg/kg''). The NRDC also reported elevated levels of pesticides, PAHs, and the metals lead, cadmium, chromium, and mercury. Esworthy et al. (2006), in a congressional report, mentions that many results to date have been controversial.

EXPERIMENTAL APPROACH

Figure 2 shows the area during flooding with sample locations shown (except the background sample site). Within this area, five sample sites were selected during the first visit. Each sample site was flagged, and coordinates were measured by global positioning system (GPS). For the first and second visits, a secondary site was established approximately 15 m (50 ft) in a cardinal direction from the primary sampling location and a shallow core obtained to 60 cm (23.6 in.). A 0–10- and 50–60-cm (0–4- and 19–24-in.) sample was acquired from these secondary sites to help establish a spatial background value for potential contaminants. During the second visit, two additional sites, 6 and 7, plus a sample from the seep line of the drainage ditch, were added to allow a direct comparison to recently available USEPA data and to evaluate a possible plume seen in newly available satellite imagery (image used in Figure 2). Additional secondary samples were obtained in a different cardinal direction during this visit. During the third visit, access was granted to federal port authority lands to acquire a potentially representative background sample. However, during the third visit, FEMA trailer construction (203 trailers) had destroyed sample sites 1, 2, 3, 4, and 7 and the drainage ditch site. FEMA contractors had removed the upper 10 cm (4 in.) of soil because of benzene contamination (Fluor-Daniels, 2005, personal communication). At each sample site, soil was collected as a surface bag sample of approximately 2 kg from the upper 5–10 cm (2–4 in.) and a core sample acquired to nominally 2 m (6.6 ft). The core samples and the bag samples were collected immediately adjacent to each other (typically less than 2–3 cm [0.8–1.2 in.] away). Bag samples were also sampled for metals and volatile organics and were sealed and returned for toxicity and bioaccumulation studies. Table 1 gives the coordinates for each primary sample location and the sampling scheme.

Core data from each numbered site were collected using a 2-ft (0.6-m)-long GeoProbe® direct push core barrel collecting a 1-in. (2.5-cm) diameter core. The core was contained within a clear vinyl tube and then capped on both ends. The core barrel was driven into the soil by a
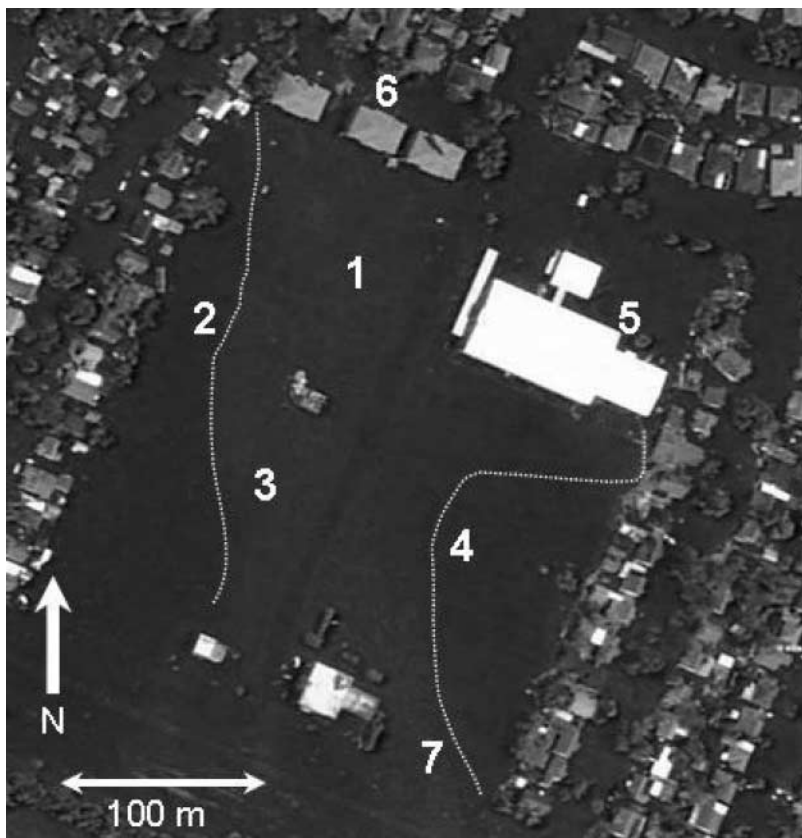
Figure 2. Sample locations within the localized study area. The figure is a gray-scale version of a global imaging satellite view of the area during flooding (Global Explorer, 2006). The dashed white lines outline a perceptible plume of an unknown material on or within the water column. The numbers represent the sample sites used during this study. The background sample location is not shown in this figure and is approximately 1250 m (4100 ft) south-southwest of sample site 1. The sample study area was approximately 200 × 300 m (650 × 985 ft) in size. Water depth was approximately 3.4 m (11 ft) deep over the study site. The large white-roofed building is Rowley Middle School.

slide hammer and extracted using a foot jack. Therefore, to acquire core from up to 2-m (6.6-ft) depth required three separate coring attempts. Typically, core recovery was near 100% for the upper section, 80–100% for the middle section, and 60–80% for the lower section. During the second and third sampling events, new core was obtained from within 10 cm (4 in.) of the initial core hole. In almost all cases, the core holes collapsed within a few hours after the core barrel was removed.

Core tubes from each location were aligned in a trough with a metric ruler and visually examined. Based on an overall analysis of site stratigraphy derived from core examination, four sample depths were selected. Figure 3 shows the general stratigraphy for the study area for the upper 2 m (6.6 ft). The vertical transition in sediment type and character was typically abrupt, from loamy, silty soils commonly containing small oyster shells (about 60 cm [24 in.] in depth) to gray and blue fat clays. A few thin beds in the clays contained higher levels of silty sand. Remnant burrows and iron nodules were observed in some of the clay core.

A 0–10-cm (0–4-in.) interval was selected (1) to be directly comparable to the soil bag samples collected for toxicity studies and 2) to use for comparison with sediment and soil data collected by the USEPA. A 50–60-cm (19–24-in.) sample depth was chosen to evaluate contaminants that might accumulate at the transition from porous soils to less-porous clay. The 120–130-cm (47–51-in.) sample depth was selected to evaluate potential contamination in the transition zone from gray silty and sandy clay to blue-gray plastic clay. The saturated zone, or water table, typically occurred between the 50–60- and 120–130-cm (19–24- and 47–51-in.) sample. The 180–190-cm (71–75-in.) sample was selected to evaluate potential contaminants within the seemingly impermeable deeper clay and within the saturated zone. It was an assumption in the field that floodwaters could not have sufficient residence time to percolate through the deeper clays of the study area to the 180–190-cm (71–75-in.) depth, and that this interval was consistently within the saturated zone.

A single-edged razor blade was used to cut the tube sections at each sample interval. Using a modified plastic syringe, approximately 5 g of sediment was acquired for each volatile organic sample and placed in a preservative-prepared 22-mL vial (10 g total for two vials), and approximately 100 cm^3 (6.1 in.^{3}) of soil was bottled for

Table 1. Coordinates of Sample Locations and Sampling Plan*

	Location		Sample Depth (cm, Number of Samples)			
	Lattitude	Longitude	0–10, 26	50–60, 30	120–130, 19	180–190, 15
Site 1	29.94498	−89.97900	1**,2[†]	1,2	1,2	1,2
Site 2	29.94474	−89.97966	1,2	1,2	1,2	1,2
Site 3	29.94396	−89.97955	1,2	1,2	1,2	1,2
Site 4	29.94371	−89.97879	1,2	1,2	1,2	1,2
Site 5	29.94448	−89.97788	1,2,3[††]	1,2,3	1,2,3	1,2,3
Site 6	29.94568	−89.97900	EPA[‡], 2,3	2,3	2,3	2
Site 7	29.94268	−89.97875	2	2	2	2
BKGD	29.93582	−89.98679	3	3	3	3

*This table reflects the actual sampling scheme where the numbers designate that a sample was acquired on trip 1, trip 2, or trip 3 for each depth interval. Only sample location 5 was sampled on all three trips because of FEMA housing construction in the study area. Sample location 6 had three sampling events because we used the original USEPA data for this location.
**First sampling trip: October 21–23, 2005.
[†]Second sampling trip: November 18–20, 2005.
[††]Third sampling trip: December 28–30, 2005.
[‡]EPA acquired sample on September 12, 2005.

metals sampling. Surface bag sediments and reference background sources were also sampled. All samples were stored in a refrigerated cooler and shipped to the laboratories of Microseeps, Inc., in Pittsburgh, Pennsylvania, within acceptable holding times. Microseeps is both a USEPA- and LDEQ-approved laboratory. Standard trip and temperature blanks were used. Each sample was acquired using new gloves and syringes to prevent cross-contamination. All sample results met applicable National Environmental Laboratory Accreditation Conference quality assurance–quality control (NELAC QA/QC) standards. For statistical analysis, we used results with *J* qualifiers because of the precision and quality of the analytical results and the fact that we were observing very low values. Each organic sample was analyzed according to the USEPA 8260 method, which is a purge and trap gas chromatography–mass spectrometry (GC-MS) method to obtain 31 key contaminant indicators from the target compound list. To determine whether metals are present, the initial samples (except soil gas samples from the surface chamber) were analyzed for Resource Conservation and Recovery Act (RCRA) metals using an atomic emission spectral technique.

DATA AND RESULTS

Table 2A and B shows the analytical results of this study. All data are available from the authors.

Establishing Background

Establishing a natural background for our sample area proved to be problematic because all areas within a reasonable distance had been flooded. Nonflooded sediments existed on the slopes of the Mississippi levee, within the Kaiser Cyanide Superfund site, Chalmette National Battlefield, and nearby industrial facilities, none of which was acceptable or accessible to our study team. Published background values for metals and volatile organics analyzed for in this study were typically not found for our specific study area, although Reible et al. (2006), citing others, provide Louisiana delta arsenic background values at approximately 10 mg/kg and LDEQ regional arsenic levels of 7 mg/kg, and Cobb et al. (2006), citing Wang et al. (2004), report values for lead (mean 784 µg/g). Pardue et al. (2005) evaluated floodwaters and found elevated levels of BTEX, lead, and arsenic. Metal results from Mielke et al. (2005) might also act as background data.

On the third sampling trip, officials granted access to the foot of the levee but several thousand feet away from the study area, and samples were obtained as a possible background reference. However, this location had also been flooded by approximately 1.25 m (4 ft) of water over an approximate 9- to 10-day period. This location was outside of the area of the floating sheen seen in Figure 2, but was upgradient or side-gradient to potential local contaminant sources. This area was the last flooded and first drained, so this may have some usefulness and represent background.

Soil Column Lithology
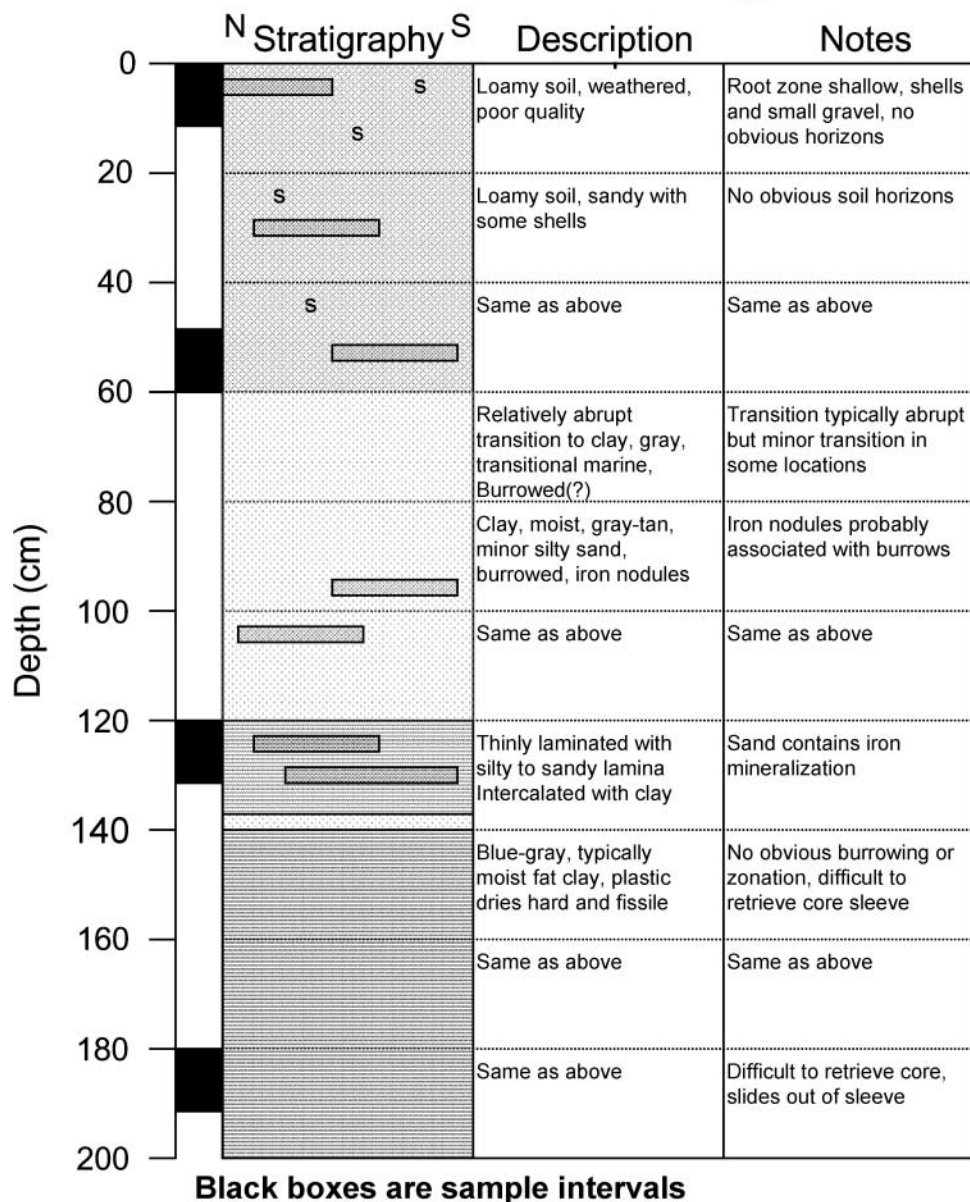
Figure 3. The soil column for the upper 2 m (6.6 ft) of the study area. This column was very similar for all sample locations. Small "s" symbols indicate depths where oyster shells were observed. For all locations, sample depths 0–10 and 50–60 cm (0–4 and 19–24 in.) were above the saturated zone. These sediments are all recent Holocene coastal marsh sediments typically deposited in the last 2000 yr.

The flood-deposited sediment was analyzed as an effort to understand potential contaminant levels in soils. Flood sediments were collected at an area approximately coincident with sample location 5 (the Rowley School playground). Figure 4 shows analytes found in the flood deposits. Elevated levels of metals (arsenic, cadmium, chromium, and lead) and volatile organics are present (refer to Table 2A; Figure 4).

Examination of the flood sediments under a binocular microscope (10× and 20×) revealed an olive-gray to dark-gray, very fine-grained silt to silty clay, with trace amounts of tan to brown silty sand. White and dark, uniformly dispersed grains, very fine silt in size, were observed throughout the samples and may possibly have been precipitated metals. The flood deposits were very thinly laminated, commonly breaking along lamination planes. The sediments were cemented and brittle but easily scraped with a probe. Dissolution, probably secondary, possibly caused by Hurricane Rita rainfall, was visible as dissolved material reprecipitated in voids and vugs. Plant materials, probably small rootlets, were also visible. The deposits were desiccation cracked when collected and had a musty, sweet organic odor. The flood deposits across the Rowley School Playground were

Table 2.

(A) Summary Analytical Results from This Study*

Sample Identification**	Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	2-Butanone	2-Hexanone
Flood seds	10,000	170,000	2800	31,000	120,000	210	1600	78	6.2
Flood seds D	10,000	140,000	2600	26,000	94,000	17	1900	69	7.1
Ditch soil	8100	180,000	1100	1700	46,000	100	1000	27	5.1
SURF 1	3100	120,000	420	9200	17,000	80		17	48
SURF 2	3500	140,000	560	17,000	35,000	80	760	9.2	130
SURF 2 D	2900	150,000	590	19,000	39,000		1100	15	110
SURF 3	3300	140,000	800	21,000	41,000		760	12	96
SURF 4	5700	78,000	350	9400	15,000			9.3	59
SURF 5	3500	120,000	450	9000	26,000		690	11	67
SURF 6	3200	110,000	640	11,000	170,000		1200	16	
EPA 8954 (6)	21,400	250,000	3570	31,800	108,000	130			
SURF 7	2600	130,000	800	14,000	48,000	80	1700	31	0.9
SURF BKGD	4900	160,000	850	22,000	34,000		1300	46	
Mean	*5410*	*139,800*	*903*	*16,340*	*53,300*	*93*	*1073*	*18.5*	*73.0*
Average deviation	*3256*	*28,200*	*533*	*5820*	*34,280*	*19*	*288*	*8.9*	*33.4*
1AP000010	4000	110,000	530	14,000	24,000			1600		15.0
1AS000010	4800	110,000	430	12,000	23,000		1200	15.0	33.0
2AP000010	3500	150,000	720	23,000	43,000	100	830	16.0	170.0
2AS000010	5800	200,000	1000	22,000	60,000	120	1800	19.0	17.0
3AP000010	5700	190,000	950	23,000	58,000	120	1500	13.0	110.0
3AS000010	5100	180,000	630	19,000	62,000	90	1700	16.0	49.0
4AP000010	7500	110,000	340	10,000	19,000		1000	12.0	5.7
4AS000010	9400	110,000	400	12,000	21,000		1000	26.0	180.0
5AP000010	3700	130,000	440	13,000	24,000		320	24.0	13.0
5AS000010	5400	140,000	550	15,000	23,000		640	3.9	
Mean	*5490*	*143,000*	*599*	*16,300*	*35,700*	*108*	*1159*	*16.1*	*65.9*
Average deviation	*1288*	*29,600*	*181*	*4360*	*16,040*	*13*	*401*	*4.6*	*58.3*
1BP000010	3600	85,000	480	10,000	19,000		1000	26.0	
1BP000010 D	4600	96,000	330	11,000	16,000		1300	6.6	
1BS000010	2100	81,000	550	12,000	23,000	80	980	9.3	
2BP000010	3400	140,000	560	17,000	29,000		1500	14.0	
2BS000010	1600	150,000	630	15,000	28,000	100	1200	19.0	85.0
3BP000010	4300	140,000	690	15,000	45,000		1900	21.0	19.0
3BS000010	4900	150,000	840	17,000	59,000	140	1600	15.0	0.7
4BP000010	6800	81,000	420	10,000	18,000		1600	9.9	
4BS000010	11,000	110,000	540	14,000	31,000		1100	12.0	
5BP000010	2800	110,000	420	13,000	22,000		1900	8.4	0.6
6BP000010	3200	97,000	520	11,000	65,000		1800	11.0	
7BP000010	2800	130,000	960	11,000	29,000		2800	13.0	
7BS000010	2400	68,000	500	8100	25,000		1900	20.0	1.0
Mean	*4115*	*110,615*	*572*	*12,623*	*31,462*	*107*	*1583*	*14.2*	*21.3*
Average deviation	*1696*	*24,142*	*128*	*2348*	*11,479*	*22*	*372*	*4.6*	*25.5*
5CP000010	8000	100,000	390	13,000	28,000		1400	17.0	
6CP000010	4700	100,000	450	11,000	57,000		940	13.0	
BKGD000010	4700	130,000	500	17,000	25,000	100	1900	12.0	

4-Methyl-2-Pentanone	Acetone	Benzene	Carbon Disulfide	Ethylbenzene	m- and p-Xylene	Methylene Chloride	o-Xylene	Toluene	Trichloroethene
3.9	490	11	51	3.8	15		3.7	34	
3.5	420	9.4	48	4.2	18	0.6	5.3	37	
3.6	280	1.1	18			1.7		5.4	
1.9	90		1.4	1	3.8		1.3	4.9	
2.7	120	1	0.8	1.5	6.1		2	6.7	
3.5	160	1.1	2.9	2.3	10		3	7.6	
1.7	90		1.2	0.7	3		0.7	1.6	
2.2	65	0.8		0.8	3.6		1.2	3.4	
1.4	130	1.4	1.6	0.6	3.2		0.9	4.3	
3.6	160	1.1	5.4	0.2		1.4	0.2	1.2	0.3
	236								
11	340		5	0.2	0.7	0.9			0.7
4	560	1.2	2.4	0.3	1.1	1.1	0.2		0.7
3.6	*195.1*	*1.1*	*2.6*	*0.8*	*3.9*	*1.1*	*1.2*	*4.2*	*0.6*
1.8	*110.1*	*0.1*	*1.4*	*0.5*	*2.1*	*0.2*	*0.7*	*1.9*	*0.2*
59.0	2.5	70.0		1.1					
1.6	78.0	0.8	1.6						
	150.0		1.3						
0.9	96.0		2.0						
3.5	120.0	1.0				1.0			
	97.0		1.0						
	46.0		1.3			2.2			
	210.0		3.5	0.3					
	130.0	1.0	1.2					2.3	
	30.0		0.8			1.7			
16.3	*96.0*	*18.2*	*1.6*	*0.7*		*1.6*		*2.3*	
21.4	*45.5*	*25.9*	*0.6*	*0.4*		*0.4*		*0.0*	
3.4	200.0	1.1	3.1	1.2	4.5	1.5	2.0	5.6	
	14.0	0.8	3.1	0.3	1.0	1.1	0.6	1.3	0.4
1.3	110.0	0.7	1.3	0.4	1.5	0.5	0.3	2.9	
4.5	260.0	1.5	1.2	0.6	2.4	1.4	0.9	5.7	
2.6	170.0	1.3	1.3	0.6	2.2	1.3	0.7	4.7	
	160.0	0.6	3.0	0.2	0.5	0.6		1.1	
2.6	190.0	0.6	1.2	0.4	1.4	1.0	0.5	11.0	
4.7	140.0	0.8	2.5	0.8	3.4	1.1	1.2	2.4	
1.9	130.0	0.4	1.4	0.2	1.3	0.7	0.4	1.0	
	88.0	0.8		0.4	1.6	1.1	0.6	2.6	
2.5	110.0	0.7	1.1	0.3	1.4	0.8	0.5	2.1	
1.5	110.0	0.6	7.3	0.2	0.6	0.8	0.2	1.2	
5.4	190.0	0.7	2.9	0.8	3.2	1.1	1.3	2.9	
3.0	*144.0*	*0.8*	*2.5*	*0.5*	*1.9*	*1.0*	*0.8*	*3.4*	*0.4*
1.2	*47.1*	*0.2*	*1.2*	*0.2*	*0.9*	*0.2*	*0.4*	*2.0*	*0.0*
	160.0	0.4	1.2	0.2	0.5				0.3
4.1	180.0		1.2	0.3	1.3	1.4	0.4		1.0
1.1	120.0	0.6	0.7	0.2	0.6	0.7	0.2		0.3

Table 2. Continued

(A) Summary Analytical Results from This Study*

Sample Identification**	Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	2-Butanone	2-Hexanone
Mean	*5800*	*110,000*	*447*	*13,667*	*36,667*	*100*	*1413*	*14.0*	
Average deviation	*1467*	*13,333*	*38*	*2222*	*13,556*		*324*	*2.0*	
Mean	**4838**	**123,000**	**568**	**14,158**	**33,692**	**106**	**1400**	**14.9**	**49.9**
Average deviation	**1632**	**27,231**	**144**	**3186**	**13,805**	**15**	**407**	**4.4**	**49.3**
LDEQ screening standards	12,000	550,000	3900	12,000,000	400,000	2300	38,000	590,000	1000[†]
EPA mean	8842	137,795	1243	16,820	77,183	127	1059	27	58.2
EPA Average deviation	4430	46,646	838	5269	57,385	57	429	17.8	38.0
Mielke et al. (2005) mean			2000	2000	100,000				
Minimum			0	0	3000				
Maximum			84,000	157,000	52,798,000				
New alluvial mean			900	700	5000				
Minimum			400	300	400				
Maximum			3000	23,000	23,000				
Presley et al. (2006) mean	7250				190,000				
Minimum	174,000				16,400				
Maximum	24,150				642,000				
Cobb et al. (2006) transect 3 mean	686,000				158,000				

(B) Summary Analytical Results from This Study[††]

Sample Identification	Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	2-Butanone	2-Hexanone
1AP050060	11,000	230,000	750	27,000	31,000	100	1200	29.0	
2AP050060	2400	160,000	210	24,000	18,000	80		10.0	12.0
3AP050060	4800	180,000	510	22,000	19,000		670	4.8	11.0
4AP050060	8200	230,000	600	21,000	22,000		830	16.0	5.1
5AP050060	2700	160,000	450	17,000	19,000		1100	8.0	
5AP050060 D	2600	180,000	740	19,000	15,000		820	2.7	1.7
Mean	*5283*	*190,000*	*543*	*21,667*	*20,667*	*90*	*924*	*11.8*	*7.5*
Average deviation	*2878*	*26,667*	*153*	*2667*	*3889*	*10*	*181*	*7.2*	*4.1*
1BP050060	3700	180,000	870	22,000	23,000		2000	6.9	1.4
2BP050060	6600	170,000	680	19,000	18,000		1200	6.6	
3BP050060	3100	130,000	310	14,000	14,000			10.0	
3BP050060 D	6100	170,000	620	17,000	17,000		850	25.0	1.3
4BP050060	8100	160,000	480	20,000	17,000		1500	19.0	0.5
5BP050060	6900	160,000	810	21,000	19,000		1800	12.0	
6BP050060	8100	190,000	1100	20,000	18,000		2300	17.0	
6BP050060 D	3200	120,000	410	20,000	17,000		1800	17.0	12.0
7BP050060	2800	130,000	330	16,000	14,000		1800	9.1	
7BP050060 D	790	120,000	190	17,000	10,000		1600	12.0	
Mean	*4939*	*153,000*	*580*	*18,600*	*16,700*		*1650*	*13.5*	*3.8*

4-Methyl-2-Pentanone	Acetone	Benzene	Carbon Disulfide	Ethylbenzene	m- and p-Xylene	Methylene Chloride	o-Xylene	Toluene	Trichloroethene
2.6	*153.3*	*0.5*	*1.0*	*0.2*	*0.8*	*1.1*	*0.3*		*0.5*
1.5	*22.2*	*0.1*	*0.2*	*0.0*	*0.3*	*0.4*	*0.1*		*0.3*
6.3	**126.6**	**4.4**	**2.0**	**0.5**	**1.7**	**1.1**	**0.7**	**3.3**	**0.5**
6.6	**48.0**	**6.9**	**1.0**	**0.3**	**0.9**	**0.3**	**0.4**	**1.9**	**0.3**
450,000	170,000	1500	36,000	160,000	18,000	19,000	18,000	68,000	100
3.5	360.9	69.7	78.1	1.2	5.6	1.0	1.7	10.8	0.5
1.4	252.0	117.9	75.4	1.1	4.0	0.2	1.2	9.9	0.2

4-Methyl-2-Pentanone	Acetone	Benzene	Carbon Disulfide	Ethylbenzene	m- and p-Xylene	Methylene Chloride	o-Xylene	Toluene	Trichloroethene
0.8	170.0	1.1	6.3	0.2		0.8		1.6	
	46.0	0.8	0.8						
	19.0	1.3		0.2	0.7		0.2	1.7	
	53.0	0.7	0.8			0.6			
	35.0	1.1	0.8	0.7		1.6	0.2	1.5	
	31.0		0.7			2.0			
0.8	*59.0*	*1.0*	*1.9*	*0.4*	*0.7*	*1.3*	*0.2*	*1.6*	
0.0	*37.0*	*0.2*	*1.8*	*0.2*	*0.0*	*0.6*	*0.0*	*0.1*	
	71.0	1.2	2.0	0.6	2.0	1.1		3.4	0.4
	45.0	0.9	1.1	0.2	0.5	0.8	0.1	1.4	
	65.0	0.8	1.0		0.4	1.0	0.1	0.9	
	170.0	1.0	2.0			0.7	0.1	1.1	
	160.0	0.8	1.5	0.4	1.9		0.6	2.1	0.6
	56.0	0.7	0.6	0.2	0.6	0.6	0.2	1.6	
0.7	110.0	0.8	1.0	0.4	1.6		0.6	2.4	
	110.0	0.8	0.8	0.4	1.5	0.8	0.5	2.8	
1.4	88.0	1.0	3.3	0.4	1.7	1.2	0.7	2.4	
1.4	100.0	0.6	7.1	0.3	1.5	0.7	0.6	1.8	
1.2	*97.5*	*0.9*	*2.0*	*0.4*	*1.3*	*0.9*	*0.4*	*2.0*	*0.5*

Table 2. Continued

(B) Summary Analytical Results from This Study[††]

Sample Identification[‡]	Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	2-Butanone	2-Hexanone
Average deviation	*2221*	*22,400*	*236*	*2080*	*2420*		*322*	*4.8*	*4.1*
5CP050060	4600	110,000	340	16,000	14,000		750	9.8	
6CP050060	8400	230,000	510	21,000	16,000	80	1800	15.0	1.1
BKGD050060	5700	220,000	470	17,000	19,000		1100	5.6	
BKGD050060 D	3300	90,000	230	13,000	10,000	60	710	5.9	
Mean	*5500*	*162,500*	*388*	*16,750*	*14,750*	*70*	*1090*	*9.1*	*1.1*
Average deviation	*1550*	*62,500*	*103*	*2250*	*2750*	*10*	*360*	*3.3*	*0.0*
Mean	**5155**	**166,000**	**531**	**19,150**	**17,500**	**80**	**1324**	**12.1**	**5.1**
Average deviation	**2271**	**32,000**	**193**	**2650**	**3100**	**10**	**445**	**5.4**	**4.4**
1AP120130	13,000	270,000	530	27,000	26,000	90	1100	24.0	9.6
1AP120130 D	4600	190,000	560	20,000	25,000	180	1900	13.0	8.5
2AP120130	6100	130,000	300	19,000	17,000	60		3.9	3.2
3AP120130	2900	130,000	240	18,000	15,000	80	620	0.6	2.4
4AP120130	5600	200,000	360	23,000	16,000		510	6.6	
4AP120130 D	5100	140,000	390	19,000	16,000		610	3.4	
5AP120130	9900	110,000	330	16,000	13,000			7.8	4.3
Mean	*6743*	*167,143*	*387*	*20,286*	*18,286*	*103*	*948*	*8.5*	*5.6*
Average deviation	*2690*	*45,306*	*91*	*2694*	*4122*	*39*	*442*	*5.7*	*2.8*
1BP120130	8200	210,000	580	19,000	15,000		1800	21.0	0.5
2BP120130	1400	290,000	340	15,000	9800		930	3.9	
3BP120130	530	130,000	480	14,000	12,000		700	13.0	
4BP120130	9900	130,000	330	17,000	15,000		1500	9.6	0.5
5BP120130	5800	200,000	480	21,000	18,000		2100	8.2	2.3
6BP120130	11,000	170,000	720	19,000	37,000		2400	19.0	0.8
7BP120130	410	130,000	260	19,000	11,000		1200	8.5	
Mean	*5320*	*180,000*	*456*	*17,714*	*16,829*		*1519*	*11.9*	*1.0*
Average deviation	*3891*	*45,714*	*125*	*2041*	*6098*		*498*	*5.0*	*0.6*
5CP120130	16,000	140,000	490	21,000	17,000		1600	7.1	
6CP120130	3200	130,000	940	20,000	19,000		2000	25.0	0.9
BKGD120130	8400	10,0000	240	14,000	11,000		1400	19.0	
BKGD120130 D	7200	120,000	250	13,000	12,000		520	5.1	
Mean	*8700*	*122,500*	*480*	*17,000*	*14,750*		*1380*	*14.1*	*0.9*
Average deviation	*3650*	*12,500*	*235*	*3500*	*3250*		*430*	*8.0*	*0.0*
Mean	**6624**	**162,222**	**434**	**18,556**	**16,933**	**103**	**1306**	**11.0**	**3.3**
Average deviation	**3400**	**43,827**	**145**	**2543**	**4496**	**39**	**532**	**6.3**	**2.5**
1AP180190	4400	110,000	330	17,000	19,000		370	9.3	
2AP180190	4500	190,000	270	12,000	8100		780	0.4	0.9
3AP180190	16,000	230,000	410	20,000	22,000		1500	2.9	
4AP180190	9800	140,000	310	19,000	19,000			7.0	
5AP180190	8000	110,000	360	15,000	14,000		510	3.3	
Mean	*8540*	*156,000*	*336*	*16,600*	*16,420*		*790*	*4.6*	*0.9*
Average deviation	*3488*	*43,200*	*39*	*2480*	*4296*		*355*	*2.9*	*0.0*
1BP180190	5500	100,000	340	16,000	17,000		640	5.4	
2BP180190	14,000	110,000	390	17,000	22,000			3.2	
3BP180190	3300	530,000	490	13,000	13,000		2200	3.6	
4BP180190	7300	130,000	650	19,000	14,000		1500		
5BP180190	3700	140,000	690	19,000	13,000		1200	0.2	

4-Methyl-2-Pentanone	Acetone	Benzene	Carbon Disulfide	Ethylbenzene	m- and p-Xylene	Methylene Chloride	o-Xylene	Toluene	Trichloroethene
0.3	*32.5*	*0.1*	*1.3*	*0.1*	*0.5*	*0.2*	*0.2*	*0.6*	*0.1*
	73.0	0.7	1.1	0.2	1.0	0.7	0.3	0.9	
	110.0	1.1	0.8	0.3	1.1	0.8	0.4	1.4	0.4
0.7	30.0	0.5	0.5	0.2	0.6	0.6	0.2		0.3
	42.0	0.4	0.5	0.2	0.7	0.5	0.2		0.4
0.7	*63.8*	*0.7*	*0.7*	*0.2*	*0.9*	*0.7*	*0.3*	*1.2*	*0.4*
0.0	*27.8*	*0.2*	*0.2*	*0.0*	*0.2*	*0.1*	*0.1*	*0.3*	*0.0*
1.0	**79.2**	**0.9**	**1.7**	**0.3**	**1.1**	**0.9**	**0.3**	**1.8**	**0.4**
0.3	**38.4**	**0.2**	**1.3**	**0.1**	**0.5**	**0.3**	**0.2**	**0.5**	**0.1**
	89.0	0.9	0.8						
	57.0	0.6							
	27.0								
	6.9								
	40.0	1.0				1.3			
	19.0					1.0			
	51.0		1.0	0.2		1.7			
	41.4	*0.8*	*0.9*	*0.2*		*1.3*			
	20.8	*0.2*	*0.1*	*0.0*		*0.2*			
0.6	70.0	0.7	2.5	0.2	0.6	0.6		1.2	0.3
	22.0	0.6	0.9	0.3	1.1	0.8	0.4	2.4	
	82.0	0.7	0.9			0.8	0.2	1.1	
	100.0	0.9	4.7	0.3	1.3		0.5	1.9	0.4
	62.0	2.0	3.2	0.6	1.9	0.4	0.5	3.1	
	160.0	1.3	13.0	0.6	2.0	1.2	0.7	3.9	
	74.0	0.5	2.5		0.5	1.1	0.1	0.9	
0.6	*81.4*	*1.0*	*4.0*	*0.4*	*1.2*	*0.8*	*0.4*	*2.1*	*0.4*
0.0	*27.9*	*0.4*	*2.8*	*0.2*	*0.5*	*0.2*	*0.2*	*0.9*	*0.1*
	6.8	1.1	2.5	0.3	1.2	1.1	0.3	1.4	0.9
	170.0	0.9	0.6	0.2		1.0	0.2	1.4	
1.0	140.0	0.9	0.8	0.2	0.8		0.3	1.2	0.9
1.4	37.0	0.6	0.4	0.2	0.8		0.2	1.1	0.4
1.2	*88.5*	*0.9*	*1.1*	*0.2*	*0.9*	*1.1*	*0.3*	*1.3*	*0.7*
0.2	*66.6*	*0.1*	*0.7*	*0.0*	*0.2*	*0.1*	*0.1*	*0.1*	*0.2*
1.0	**67.4**	**0.9**	**2.6**	**0.3**	**1.1**	**1.0**	**0.3**	**1.8**	**0.6**
0.3	**38.4**	**0.3**	**2.0**	**0.1**	**0.4**	**0.3**	**0.1**	**0.8**	**0.3**
	46.0								
	23.0								
	7.5								
	32.0		0.7			1.1			
	17.0			0.3		2.2			
	25.1		*0.7*	*0.3*		*1.7*			
	11.1		*0.0*	*0.0*		*0.6*			
	25.0	0.6	0.5		0.5	0.8	0.1	1.1	
	31.0	0.8	0.6			0.7	0.1	1.2	
	16.0	0.4	0.5		0.4	0.7		0.8	
	37.0	0.6	0.4	0.4	1.4		0.5	2.1	0.5
	27.0	0.6	1.6	0.3	1.4	0.5	0.4	1.6	

Table 2. Continued

(B) Summary Analytical Results from This Study[††]

Sample Identification[‡]	Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	2-Butanone	2-Hexanone
6BP180190	3200	120,000	290	18,000	15,000		2200	6.4	
7BP180190	1300	120,000	340	15,000	12,000		1300	2.8	
Mean	*5471*	*178,571*	*456*	*16,714*	*15,143*		*1507*	*3.6*	
Average deviation	*2967*	*100,408*	*132*	*1755*	*2490*		*462*	*1.5*	
5CP180190	14,000	350,000	620	14,000	16,000		3000	13.0	
BKGD180190	7400	550,000	550	15,000	12,000		2500	6.2	
Mean	*10,700*	*450,000*	*585*	*14,500*	*14,000*		*2750*	*9.6*	
Average deviation	*3300*	*100,000*	*35*	*500*	*2000*		*250*	*3.4*	
Mean	**7314**	**209,286**	**431**	**16,357**	**15,436**		**1475**	**4.9**	**0.9**
Average deviation	**3616**	**117,551**	**120**	**2071**	**3198**		**675**	**2.8**	**0.0**

*For the surface and 0–10-cm (0–4-in.) core data.

**The sample label scheme is as follows: first digit is sample sites 1 through 7, the second digit is sample visit (A = first, B = second, C = third), the third digit indicates primary or secondary sample site (P is primary, and S is secondary), the next six digits indicate sample depth interval (i.e. 000010 is 0–10 cm (0–4 in.) and 180190 is 180–190 cm [70–74 in.]), and the final digit if present indicates D for a duplicate sample. Values are in micrograms per kilogram and were converted from milligrams per kilogram from other studies if listed. Organic analytes with 18 or less detections are not shown. The EPA sample 8954 is included because it was used for the first sample site 6 surface data set. Each sample set is followed by a mean and average deviation. Each grouping of data is followed by a summary mean and average deviation shown in italics. The EPA means and average deviation are shown for those samples used as comparison in this study (USEPA, 2005). Values from previous workers listed in the text are also shown. Screening levels are from LDEQ (2003).

[†]Data are from ATSDR (1995).

[††]For the 50–60-cm (20–23-in.), 120–130-cm (47–51-in.), and 180–190-cm (71–74-in.) core data.

[‡]The sample numbering system is the same as described in Table 2A.

rippled with a drainage flow direction approximately north-northwest. No obvious hazardous materials or substances were seen under binocular examination.

USEPA Data

This study compared 52 USEPA sample results near the study area and reviewed numerous others. For organics, only 6 of the 52 samples contained analytes above detection limits (12%). This is a lower percentage than results noted in Pardue et al. (2005). Three samples had levels of carbon disulfide with a mean of 3.6 µg/L, and six samples returned levels of acetone with a mean of 116.4 µg/L. Values for metals were generally low, with arsenic, lead, and chromium approaching USEPA or LDEQ trigger levels. This study acquired only one water sample from the drainage ditch that transected the sampling area. Acetone (7.4 µg/L), ethylbenzene (0.2 µg/L), and trichloroethene (0.4 µg/L) were found in this sample. Averaged USEPA results are shown in Table 2A.

Surface Samples

Soil from surface samples were most likely to come into contact with humans and animals and were used for toxicity and bioaccumulation studies. Toxicity testing results are reported in Harmon and Wyatt (in press). Comparing sample populations (F-test for variance) from the surface bag samples with the 0–10-cm (0–4-in.) core samples acquired at the same time indicated that both populations were similar as expected (i.e., for arsenic, $F = 0.27 < 0.32 = F_{crit}$).

Comparing the USEPA data used in this study (acquired across a broader continuum of time) with our surface bag samples yielded a difference in populations. However, comparing our samples from October 24, 2005, with USEPA samples from October 29–31, 2005, we found that our surface bag samples and the EPA samples were from similar populations ($F = 0.04 < 0.27 = F_{crit}$). Comparing bag samples with core 0–10-cm (0–4-in.) samples combined across all three sampling events suggests that these populations may not

4-Methyl-2-Pentanone	Acetone	Benzene	Carbon Disulfide	Ethylbenzene	m- and p-Xylene	Methylene Chloride	o-Xylene	Toluene	Trichloroethene
	43.0	0.6		0.2	0.7	1.0	0.1	1.8	
	48.0	0.4	0.6			0.8		0.9	
	32.4	*0.6*	*0.7*	*0.3*	*0.9*	*0.8*	*0.2*	*1.4*	*0.5*
	8.8	*0.1*	*0.3*	*0.1*	*0.4*	*0.1*	*0.2*	*0.4*	*0.0*
	110.0	0.5	0.9	0.3	0.9	1.0	0.2	1.2	0.7
	32.0	*0.7*	*0.5*	*0.2*		*0.5*	*0.2*		*0.3*
	71.0	*0.6*	*0.7*	*0.3*	*0.9*	*0.8*	*0.2*	*1.2*	*0.5*
	39.0	0.1	0.2	0.1	0.0	0.3	0.0	0.0	0.2
	35.3	**0.6**	**0.7**	**0.3**	**0.9**	**0.9**	**0.2**	**1.3**	**0.5**
	15.3	**0.1**	**0.2**	**0.1**	**0.4**	**0.3**	**0.1**	**0.4**	**0.1**

be similar for acetone ($F = 0.6 > 0.26 = F_{crit}$), lead ($F = 7.92 > 3.5 = F_{crit}$), or arsenic ($F = 0.267 < 0.268 = F_{crit}$). This may be caused by slightly different sampling volumes (the bag samples were homogenized sediments from the upper 5–10 cm [2–4 in.] over an excavated diameter of typically 20–30 cm (8–12 in.) and typically included roots but not grass, and the 0–10-cm (0–4-in.) core was a smaller volume 2.5 × 10 cm [1 × 4 in.] not containing roots) or because of changes in analytical concentrations of the core samples in subsequent sampling events.

In all surface samples, volatile organic results from the USEPA, or from this study, only 11 constituents were found in 18 or more samples above detection limits: acetone (83), carbon disulfide (65), 2-butanone (38), ethylbenzene (30), m- and p-xylene (30), 4-methyl-2-pentanone (28), benzene (27), o-xylene (26), toluene (24), 2-hexanone (23), and methylene chloride (23). Of these detections, 38 of the 83 acetone hits and 35 of 65 carbon disulfide hits were from the immediate study area, and most were from the analyses acquired as part of

this study. The choice of 18 detections for volatile organics is setting a 10% sample of the 180 surface samples used for analysis. Less than 18 analytical detections of a given constituent across the 180 samples were considered sporadic.

Core Samples

The higher number of 0–10- and 50–60-cm (0–4- and 19–24-in.) samples (see Table 1) includes the addition of the secondary sample locations obtained during the first and second trips. The secondary samples were considered in the data used for surface sample comparisons, but are not considered in the analysis of core samples by depth. Removing these samples gives a core sample count of 0–10 cm (0–4 in.) (16) and 50–60 cm (19–24 in.) (20). Figure 5 shows the RCRA metals from the core samples averaged by depth and combining all sampling events.

Figure 6 presents data for arsenic by sample depth and sampling event. Several results exceeded LDEQ

Figure 4. Constituents found in the flood deposit.

Analytes Found in Flood-Deposited Sediment
(this study)

Volatile organics were less prevalent in deeper samples. Figure 8A–C shows the volatile organic concentrations from the core data averaged by sample depth. In most cases, concentrations decrease with depth. Acetone was the most abundant volatile organic found during this study (see Figure 4; Table 2A, B), and results are shown in Figure 9.

DISCUSSION AND CONCLUSIONS

On the first visit, field observations of a shallow water table and readily observable seepage through soils into the drainage ditch supported our premise that floodwaters could saturate and impact underlying soils. The drainage ditch provided a continuous observation portal for the water table and helped establish a reference point for sampling. Additionally, a sweet organic vapor odor was noted in core and flood deposits, and a cooling could be felt through our gloves, possibly the evaporative effect of volatile organics. A sheen observed on the satellite image (Digital Globe, 2005) used in Figure 2 may be a contaminant, possibly floating petroleum or chemical products, mobilized by the floodwaters from sources south of the site and supports the potential for localized contamination. However, the apparent plume

screening levels from the 110–120- and 180–190-cm (43.3–47- and 71–75-in.) sample intervals, as well as in the early USEPA surface sample. Lead values are shown in Figure 7.
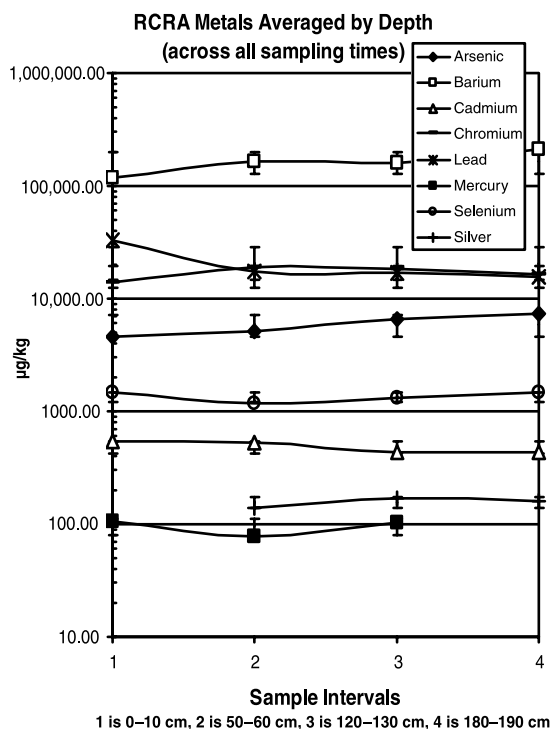
Figure 5. RCRA metals averaged by depth sampled. Error bars represent the first Standard Deviation (SD). Data are relatively uniform with depth, but barium and arsenic increase with depth, whereas lead and cadmium decrease with depth. The greatest change occurs between the 0–10-cm (0–4-in.) depth and the 50–60-cm (19–24-in.) depth or the 50–60-cm (19–24-in.) depth and the 120–130-cm (47–51-in.) depth, possibly related to stratigraphy and the sand-clay contacts (see Figure 3).

Arsenic Levels by Depth (cm) and Sample Event
Sample Site by Visit (i.e., 4-1 is Site 4, Visit 1; 4-2 is Visit 2, etc.)
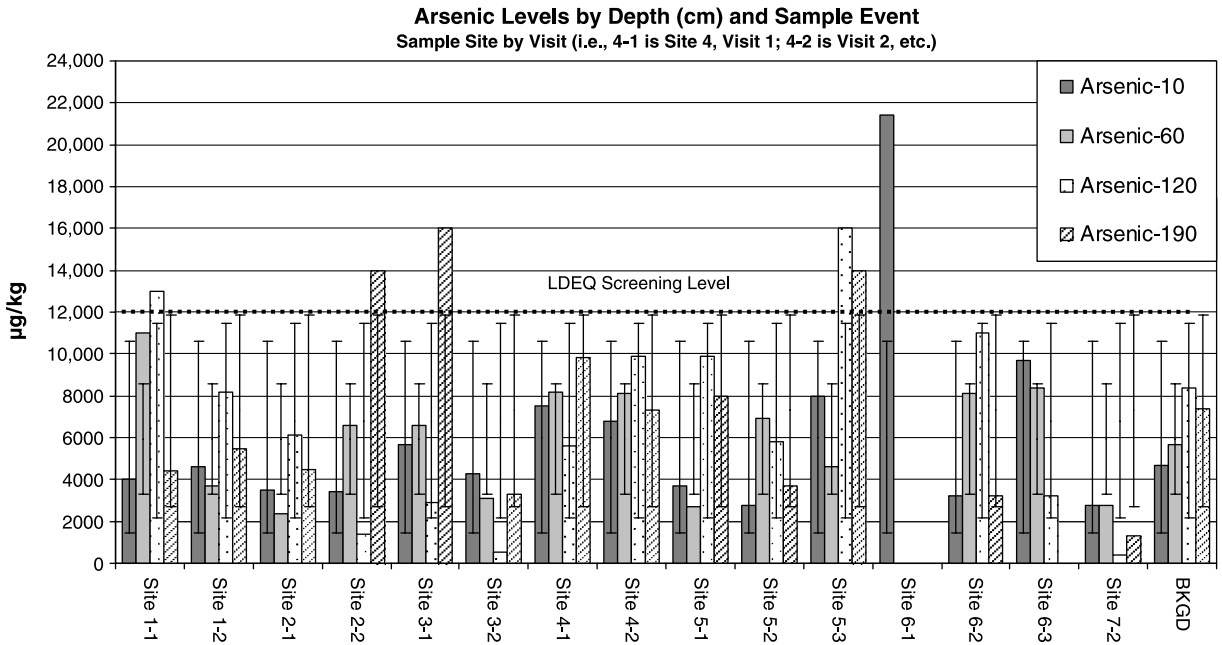
Figure 6. A comparison for arsenic across all sample depths and events. Arsenic concentrations were generally higher in deeper samples. Several arsenic values exceed LDEQ screening levels commonly from the 120–130- or 180–190-cm (47–51- or 71–75-in.) depths. Only site 6, from the first sample event (the USEPA 8954 sample data), exceeded arsenic levels in the surface sediments. Error bars represent the first SD.

Lead Levels by Depth (cm) and Sampling Event
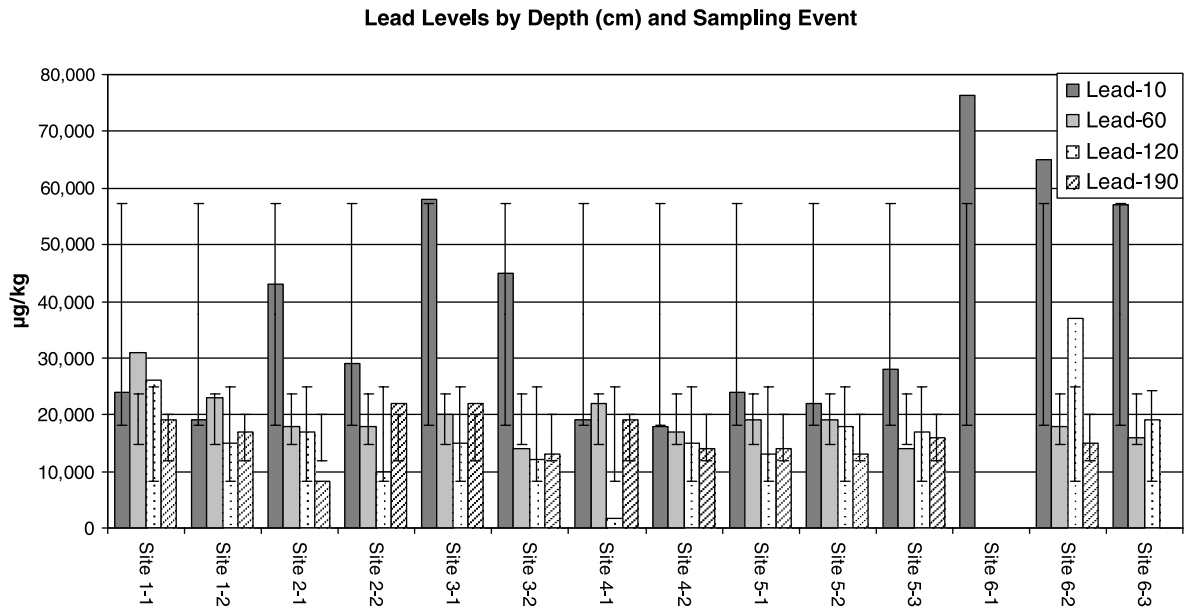
Figure 7. A comparison for lead across all sample depths and events. Lead values from this study did not exceed LDEQ screening levels. However, lead values were typically higher in the surface samples and lower in the deeper samples, the inverse of arsenic. The surface lead values from site 6 were generally higher than the other sample sites. Error bars represent the first SD.

Average Ketone Values by Depth
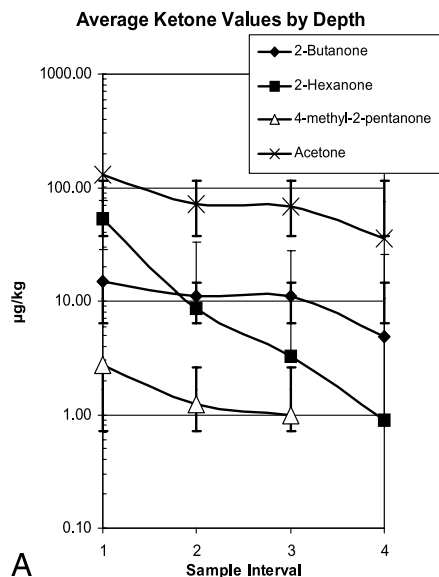
A

Average Benzene, CDS, Ethylbenzene Values by Depth
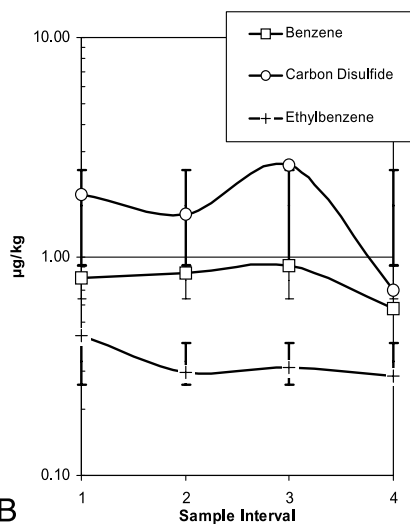
B

Average Xylenes, MethyleneChloride, Toluene Values by Depth
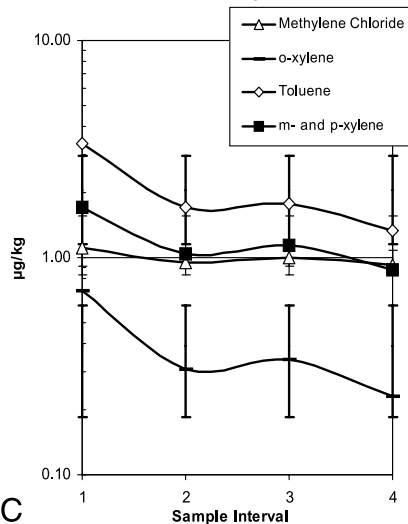
C

also possibly contains silty or muddy water caused by flow because of pumping. Tarry residue present in high water marks on buildings suggest the presence of floating organics. Based on analytical data, both the residue and vapor odor could have been from the combined effects of acetone, toluene, 2-butanone, and possibly other volatiles. Early field sampling by others must have discovered benzene, leading to FEMA removing the topsoil in our study area. This study did not find benzene in high concentrations (overall average of 2.1 µg/kg), although acetone (mean 106.9 µg/kg) was present. It was not the purpose of this study to define sources of detected chemicals.

Flood sediments remained on impermeable flat surfaces like sidewalks, floors, and playgrounds. In the grassy and barren soil areas, the flood deposits were not present as stratified deposits, indicating that this material had most likely percolated into and commingled with the underlying sediments. However, some small patches of the gray flood sediments remained trapped in tufts of grass. A redepositing or washing away of flood sediments caused by floodwater pumping also was not observed, further suggesting percolation into the soils. Only in places where the substratum was impermeable, i.e., the Rowley School Playground, had flood deposits not percolated into the soils below.

Detectable levels of all eight RCRA metals and numerous volatile organics were found in soils sampled for this study. Table 2A and B lists all results with means and average deviations per sample visit and depth. Sporadic findings of silver (11 detections), 1,1,2-trichloroethane (3 detections), 1,1,2,2-tetrachloroethane (2 detections), bromethane (1 detection), isopropylbenzene (2 detections), and tetrachloroethene (4 detections) were not considered further.

RCRA Metals

Although all eight RCRA metals were found during this study, only arsenic approached or exceeded LDEQ screening levels (Figure 5). Arsenic values were typically higher in deeper samples as was barium. Overall arsenic values from this study have a mean of 5854 µg/kg and range of 410–21,400 µg/kg. Arsenic values from

Figure 8. (A–C) Volatile organics averaged by depth sampled. Error bars represent the first SD. Sample interval 1 is 0–10 cm (0–4 in.), 2 is 50–60 cm (19–24 in.), 3 is 120–130 cm (47–51 in.), and 4 is 180–190 cm (71–75 in.). Values generally decrease with depth.
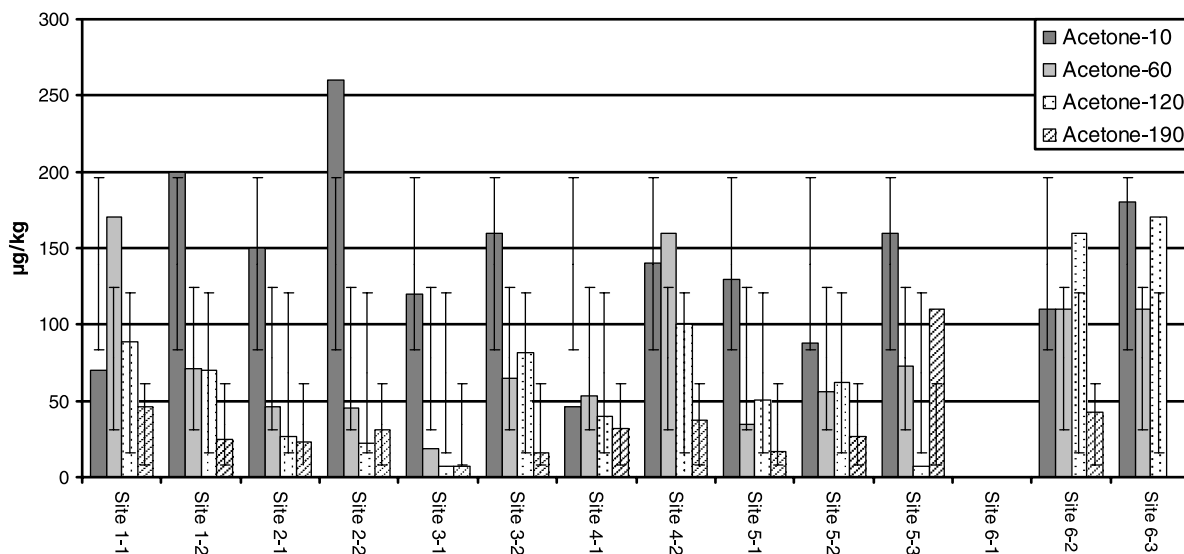
Figure 9. A comparison for acetone across all sample depths and events. For all sample sites except 5 (no data for site 6), the surface values for acetone increased between the first and second sampling event. For sites 5 and 6, the levels increased between the second and third sample events. For all sites except 1, the acetone levels increased at the 180–190-cm (71–75-in.) sample depth between successive sample events. Error bars represent the first SD.

Presley et al. (2006) are consistent but somewhat elevated as compared with those from this study, whereas values from Mielke et al. (2005) have a broader range but higher mean. The increase in barium with depth may be associated with higher clay levels.

For arsenic concentrations by depth, a simple analysis of variance across the first two sampling events suggests that there is a significant difference between the 0–10-cm (0–4-in.) sample results and the 50–60-cm (19–24-in.) depth ($F = 0.359 > 0.233 = F_{crit}$), but not between deeper depths. Additionally, for the October sampling (first event), there is a significant difference between the 0–10-cm (0–4-in.) depth and the 120–130- and 180–190-cm (47–51- and 71–75-in.) sample populations (i.e., $F = 0.185 > 0.157 = F_{crit}$) not seen in the November sampling. This suggests that the arsenic concentrations in the near surface in October are anomalous and related to Katrina flooding. This result does not particularly support our initial hypothesis that contaminants may be carried into the underlying soils by flood waters, at least for arsenic. Overall, by depth, RCRA metals were relatively uniform in concentration.

Lead was persistent in all samples, but at levels below LDEQ screening values. Mielke et al. (2005), in his study for metals, found lead ranging from 3 to 52,798 mg/kg, with a mean of 100 mg/kg. This is consistent with the lead averages from Table 2, where the mean lead value from this study was 27,911 μg/kg, rang-

ing from 8100 to 170,000 μg/kg and is enveloped by Mielke's numbers. Presley et al. (2006) found lead ranging from 16.4 to 25.15 μg/g, with an average of 190 μg/g generally higher than ranges found in this study (mean = 27,911 μg/kg; range = 8100–170,000 μg/kg).

The results for lead are somewhat similar to those for arsenic. For the October sampling, the 0–10-cm (0–4-in.) values are significantly different than the deeper values ($F = 9.42 > 6.39 = F_{crit}$) for the 0–10-cm (0–4-in.) and 50–60-cm (19–24-in.) comparison. For November, the 0–10-cm (0–4-in.) results are significantly different than the 50–60- and the 180–190-cm (19–24- and 71–75-in.) results. Interestingly, the comparison between sampling events by depth suggests a difference between the 0–10-cm (0–4-in.) October and November samples, no difference for the October–November 50–60-cm (19–24-in.) samples, a difference for the 120–130-cm (47–51-in.) samples, and no difference for the 180–190-cm (71–75-in.) samples. Overall lead values in soils are lower in all samples than the values observed in the flood-deposited sediments.

An interesting trend (Figure 10A) is noticed in the change of metal concentration with time and depth. As depth increases, concentrations tend to be lower in the second sampling event, but at a decreasing rate with depth. Also, the number of samples with concentrations remaining the same between events increases with depth. This figure indicates that metal concentrations

Figure 10. Simple trend analysis for concentration change between sample events by depth. Figure A, top, shows changes in RCRA metal values by depth interval between subsequent sampling events. For example, in the 50–60-cm (19–23-in.) depth interval, more RCRA metal analytical values tended to decrease between subsequent sampling events but at a lessor rate than the 0–10-cm (0–4-in.) depth samples and more than the 120–130-cm (47–51-in.) depth samples. Note the increasing rate of sample with progressively higher values with depth and the corresponding decrease in samples with progressively lower values. The figure in B shows the results for the volatile organics which show mixed results.
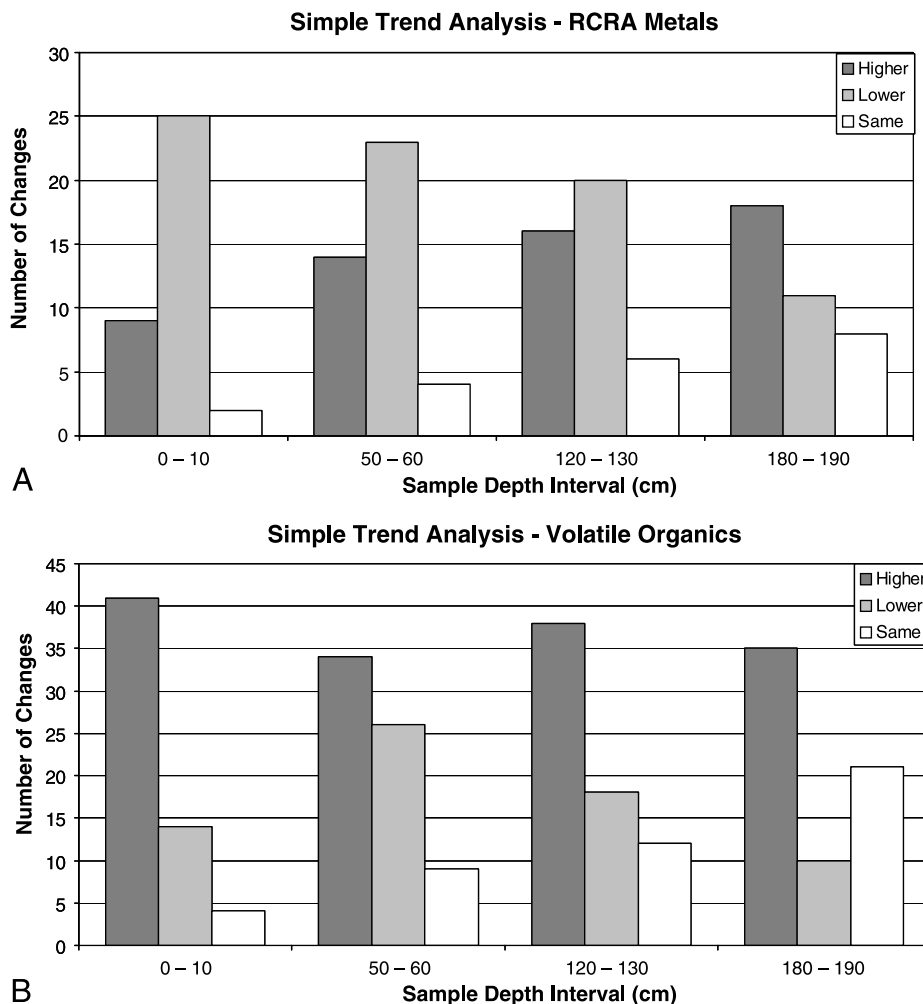
in the near surface have a higher rate of change with time than sediments in the deeper clays, and that the rate of change is progressively smaller with depth. Also indicated is that metal concentrations are increasing in the clays while diminishing in the shallow soils (refer to Figure 3). This explains why Figure 5 indicates an averaged uniformity of metals with depth, but Figure 10A indicates progressive change. Metals in floodwaters may have been deposited in the soils and are now leaching downward to the impermeable clays, or metals in deeper sediments were mobilized by the saturating floodwaters. Future work may want to explore this further.

Overall, the metals and concentrations found during this work were comparable to previous studies. The persistence of occurrence and generally elevated levels, while typically lower than LDEQ trigger levels, would suggest a low level of contamination throughout the study area. Researchers at Louisiana State University (LSU) (LSU AgCenter, 2005) found metals similar to what would be expected in typical storm runoff,

except for lead, and believed that dilution of heavy metals is why contaminant elevations were not greatly higher. This phenomenon may explain the levels of metals found in this study.

Volatile Organics

This study assumed that the volatile organic analysis would discover secondary products from gasoline and petroleum contamination. Gasoline and general petroleum products floating on the floodwaters had been noted by many sources. Although in low amounts, the presence of benzene (mean 2.1 µg/kg), toluene (mean 3.6 µg/kg), ethylbenzene (mean 0.6 µg/kg), carbon disulfide (mean 3.4 µg/kg), and o- and m- and p-xylenes (mean 0.7 and 2.2 µg/kg, respectively) is thought to indicate widespread petroleum distribution. These may have been in the soil pre-Katrina because of the proximity to local refineries or may be caused by petroleum

products in the floodwaters. Field observation of tarry residues on buildings at high water marks were apparently from floating petroleum products.

The presence of the ketones, particularly acetone, was unanticipated. Acetone (mean = 106.9 µg/kg) was ubiquitous throughout our study area and was found in all samples. Almost as prevalent was 2-butanone (mean = 13.8 µg/kg); however, 2-hexanone (mean = 29.7 µg/kg) and 4-methyl-2-pentanone (mean = 4.2 µg/kg) were only seen in approximately half of the samples in this study.

Comparing acetone values between sample event and depth interval yielded mixed results. Looking at all organics generally, however (Figure 10B), indicates that volatile organic concentrations generally increased between sampling events 54% of the time, but decreased in overall concentration (see Figure 8A–C). The number of samples that remained the same between sampling events (17%) increases with depth, suggesting a stability of organic concentration in the clays (refer to Figure 3). The number of organic concentrations that trended lower between sampling events varied by depth, but generally decreased from the 50–60-cm (19–24-in.) interval and deeper. Therefore, the concentration of organics at the surface is apparently more variable than deeper intervals, but somewhat more stable at 50–60 cm (19–24 in.) or the top of the loam-clay contact. Future research may want to explore this further.

The difficulty of statistical interpretation of pre-Katrina analytical values versus post-Katrina analytical values noted by Reible et al. (2006) was also noted in this article. The lack of established background values and the apparent high variability of RCRA metals and volatile organics in an established neighborhood and industrial area makes trend analysis difficult. Although prolonged flooding from levee failure is unique to New Orleans, we believe that the potential hurricane-related lowland flooding with waters containing metal and organic contaminants is possible along the entire southeastern coastline. We suggest that background soil values for potential contaminants be collected in all areas prone to hurricane-induced flooding.

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