Chemical Quality of Depositional Sediments and Associated Soils in New Orleans and the Louisiana Peninsula Following Hurricane Katrina

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Hurricane Katrina made landfall on the Louisiana peninsula south of New Orleans on Aug 29, 2005. The resulting storm surge caused numerous levy breaches in the parishes of New Orleans as well as on the Louisiana peninsula. This study was conducted to determine the concentrations of inorganic and organic constituents in sediments and associated soils in New Orleans parishes and the Louisiana peninsula after the floodwaters had been removed and/or receded following Hurricane Katrina. A total of 46 sediment and soil samples were analyzed that were collected throughout New Orleans and the Louisiana peninsula. Approximately 20% of the sediment samples were analyzed, including shallow sediment samples from locations that included the top and beneath automobiles, in residential and commercial areas, and near refineries. Gasoline constituents, pesticides, and leachable heavy metals were analyzed using headspace gas chromatography/mass spectrometry (GC/MS), organic extraction GC/MS, and inductively coupled plasma/mass spectrometry, respectively. A significant number of samples had leachable As and Pb concentrations in excess of drinking water standards. The remaining metals analyzed (i.e., Cd, Cr, Cu, Hg, and V) generally had much lower leachable levels. Of the gasoline constituents, only benzene was observed above the limit of detection (of 5 μg/kg), with no samples observed as being above the method detection limits of 10 μg/kg. For the 18 pesticides analyzed, most were in the nondetectable range and all were in trace amounts that were orders of magnitude below regulatory guidelines.

Introduction

On Aug 29, 2005, Hurricane Katrina made landfall in Louisiana. The storm tracked from the Gulf of Mexico with sustained Category 5 winds about 150 miles to the south of the Louisiana's peninsula. By 1110 UTC Aug 29, 2006, Hurricane Katrina became a Category 3 storm and made landfall near Buras, LA, on the peninsula that extends southward into Louisiana's rich but fragile marsh system (*1*). The peninsula hosts a series of small communities that support the state's fishing industry. As a result of Katrina, nearly the entire peninsula was devastated, including much of the fleet that supported the fishing industry. The storm surge was recorded at 14.7 m NOAA buoy 42020, Public Advisory 25b, and spilled into the narrow strip of land between the levees, removing homes from their foundations, scattering fuel oil tanks and their contents, and damaging oil refineries. After the storm passed, boats, vehicles, and debris from homes, businesses, and cemeteries remained in numerous piles along the peninsula.

After making landfall on the peninsula, Katrina moved northward, passing New Orleans about 55 km east of St. Bernard Parish. Sustained at a Category 3 hurricane, Katrina created a storm surge within Lake Pontchartrain that pushed water over the levees protecting the city (*1*). This overtopping of the levees caused segments of the levee system to erode to the point of failure. The torrent of water that followed devastated the parishes of New Orleans. Homes at the failure points were completely destroyed and created large moving debris piles. Vehicles, boats, motorcycles, electrical transformers, and household and automotive chemicals all were dispersed throughout neighborhoods and came to rest along with the sediments from Lake Pontchartrain throughout the affected neighborhoods. Structures that were unaffected by the debris flows and swift moving water became depositional areas for sediments. What remained in the wake of this event is the realization that cleanup of the debris and sediment, and long-term exposure of the repopulating residents to it, could pose a substantial health hazard.

The contribution of water and associated sediment from Lake Pontchartrain during this event may be largely responsible for the concentrations of contaminants observed in recent post-Katrina studies (*2*, *3*). Lake Pontchartrain has been a long-term sink for environmental contamination, primarily because it receives all the drainage from New Orleans' industry and population (*4*) during rainfall events. Water column samples have been shown to contain numerous U.S. Environmental Protection Agency priority pollutants (*5*), and the presence of large concentrations of herbicides have been documented within the Lake's sediments (*6*, *7*). Furthermore, Noakes (*8*) reports large concentrations of lead, chromium, and barium in Lake's sediments, on the basis of use of the continuous sediment sampling and analysis system (*8*). Given the extreme mixing of the Lake's sediments with the floodwaters of New Orleans, it is expected that the sediment deposited within the dewatered areas will contain large concentrations of trace metals and organic compounds.

The objective of the fieldwork was to catalog the storm's affects on structures, analyze the cause of levee failures, and characterize the contamination that remained as a result of the mixing of new contaminants with those already associated

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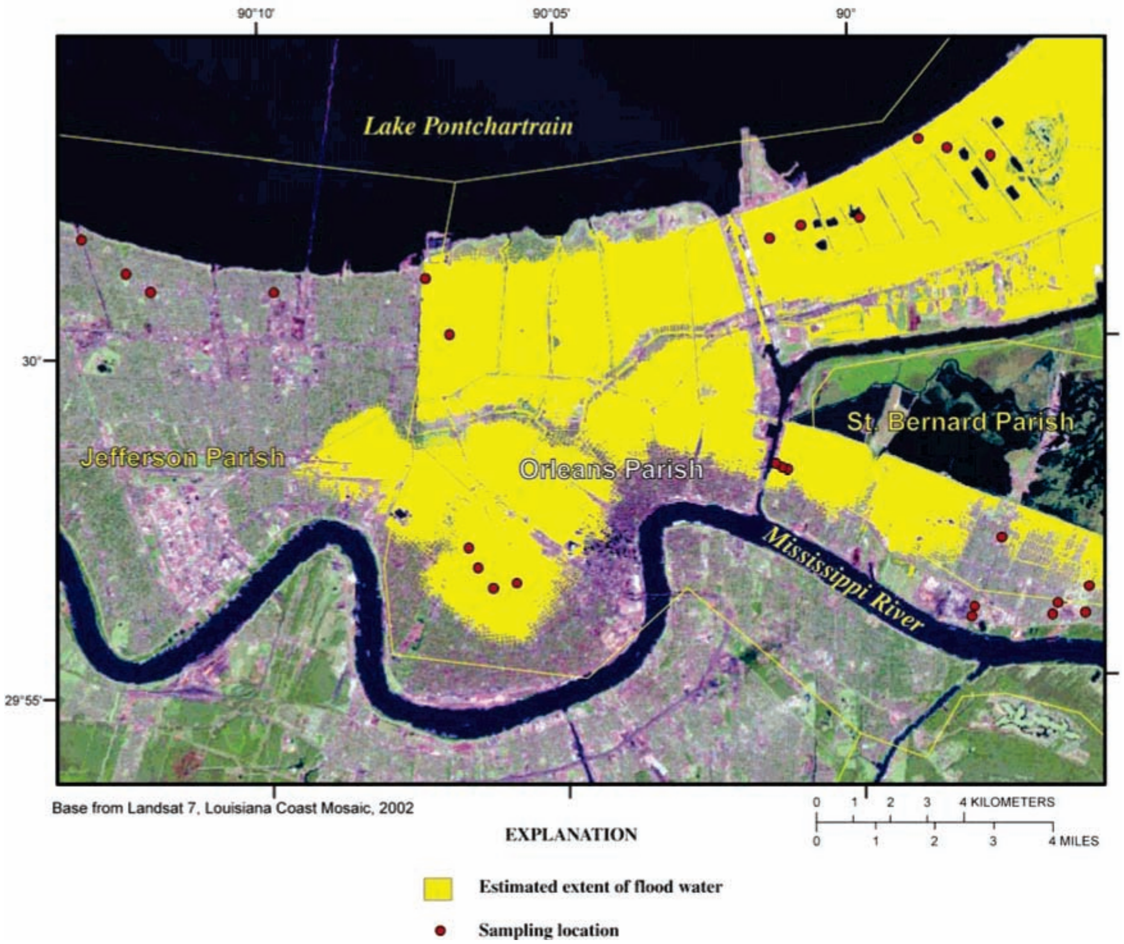

Base from Landsat 7, Louisiana Coast Mosaic, 2002

FIGURE 1. Probable distribution of sediment deposits resulting from flooding associated with the levee failures following hurricane Katrina based on significant floodwater intrusion based on 5 m resolution light imaging detection and ranging (LIDAR) data and water surface level of Lake Pontchartrain. Dots show the general locations of all sediment samples collected in New Orleans' Jefferson Parish, New Orleans Parish, and St. Bernard Parish.

with the sediments of the New Orleans levee canals and Lake Pontchartrain. To achieve this objective, a team of U.S. Geological Survey (USGS) and University of Missouri−Rolla (UMR) scientists collected samples in the devastated area in October 2005, 1 month after Hurricane Katrina made landfall along Louisiana's peninsula. To study potential contamination in sediments, the strategy was to collect many sediment samples along the peninsula and within communities of New Orleans affected by the flood including near levee breaks, in neighborhoods, near businesses, and in industrial complexes. This paper discusses the results of chemical analyses of a subset of sediment samples taken over a wide region that includes Jefferson Parish, Orleans Parish, St. Bernard Parish, and the peninsula following the dewatering of the affected areas.

Several recent studies have reported total metal concentrations in sediments and soils in post-Katrina New Orleans. Cobb et al. (*9*) examined 27 metals in sediments in New Orleans. Their study, however, included four transects within Orleans Parish. Specifically, the Cobb et al. study included little or no data from Jefferson Parish or St. Bernard Parish, the refinery region in southeast New Orleans, the northeast region of Orleans Parish along the lakefront area, or the Louisiana Peninsula south of New Orleans through which Hurricane Katrina passed. A second study conducted by van Metre et al. (*10*) evaluated both heavy metals and organic contaminants in sediments of Lake Pontchartrain and along its lakeshore area of New Orleans. On the basis of the samples from near Lake Pontchartrain, van Metre et al. concluded that contamination was limited spatially and probably transitory.

The study reported in the manuscript reports the concentrations of organic contaminants and leachable metals from a wide range of sites across Orleans, St. Bernard, and Jefferson Parishes of News Orleans as well as the entire distance of the Louisiana peninsula to beyond Venice, LA.

Materials and Methods

Locations, Sites, and Sampling. A total of 238 sediment samples were collected over the period Oct 6−18, 2005, in New Orleans and along Highway 23 on the Louisiana peninsula. In this preliminary study, a total of 46 of 238 samples collected were analyzed. The specific locations of these samples in New Orleans were in Jefferson Parish, Orleans Parish, and St. Bernard Parish. The estimated extent of floodwater and sediment deposition is provided in Figure 1. This estimate was produced by projecting the floodwater surface elevation of Lake Pontchartrain over 5 m light detection and ranging (LiDAR) data for New Orleans to determine which areas were covered by floodwaters. Figure 1 is a reprojection of that area over LandSat 7 imagery and provides an estimate of where sediment was likely to have deposited. This estimate will be refined in a follow-up study using spectral reflectance of the earth surface in relation to ground-truth data collected at the time of this deployment. For example, the four western-most sample sites in Jefferson Parish (Figure 1) are known to have received floodwater of at least 0.5 m on the basis of physical observation of effects

FIGURE 2. Sediment samples were taken from many locations throughout the city and Louisiana peninsula.

(e.g., water marks and interior flooding of homes) as well as discussions with local residents.

Sample locations were selected to provide a cross-section of residential, business, and industrial (refinery) areas. Sites included neighborhoods at the 17th Street Levee breach, at the Industrial Levee breach, in neighborhoods of the Brookmoor District, and near refineries in eastern New Orleans along the Mississippi River. Samples were taken along Highway 23 south of New Orleans including in Empire, LA (near the location where the eye of Hurricane Katrina passed through on Aug 29, 2005) to sites a few miles beyond Venice, LA, near the gulf fishing fleet marina.

Two procedures were used for sample collection: a coring procedure and a surface sediment collection procedure. In the coring procedure, a 2 cm diameter hand-held soil corer was used to take a “shallow” core (0−10 cm deep), in addition to a “deep” core (10−20 cm) collected only as a subset of sites. The coring samples were taken to allow assessment of how contaminants may have penetrated into the ground and/or the baseline concentrations of contaminants not caused by the flooding. Sediment samples were also taken from the top 1 cm of sediment on the ground, from the tops of and beneath automobiles, from sidewalks, and from the insides and outsides of structures. Examples of sediment collection sites are shown in Figure 2.

All soil and sediment samples were placed in 60 mL amber glass vials with Teflon-lined caps. The samples were labeled and immediately double-bagged into plastic bags and placed in the dark in a cooler. Samples were kept cold and in the dark until analysis in the Environmental Research Center at UMR. Of the 238 samples collected, a subset of 46 selected samples was analyzed using the organic and inorganic chemical methods described below with at least one surface (shallow and/or surface sediment) sample included from each location. Furthermore, at the time of sample collection, sediment depth was measured and recorded so an estimate of the amount of deposition could be calculated.

Reagents, Standards, and Samples. All pesticide analytical standards were supplied by Sigma (St. Louis, MO). Benzene, toluene, ethylbenzene, *o*-xylene, *m*-xylene, and *p*-xylene (BTEX) were supplied by Fisher Scientific (Chicago, IL). Individual stock standard solutions were prepared from high-purity substances in 10 mL volumetric flasks. All stock standard solutions were stored in a freezer in the dark.

The internal standard for pesticides, d_{10}-phenanthrene (CAS 1517-22-2), was purchased from Sigma (St. Louis, MO). The internal standard for BTEX, benzene-d_5 (CAS 13657−09-5), was purchased from CDN-isotopes (Quebec, Quebec, Canada). Methylene chloride (DCM), hexane and methanol were reagent grade solvents purchased from Fisher Scientific (Chicago). All trace metal standards, As, Cd, Cr, Cu, Hg, Pb, and V, were purchased from Fisher Scientific (Chicago, IL). Water (MQ) was purified from distilled water using a Milli-Q RG system (Millipore, Billerica, MA).

BTEX by Headspace Organic Chemical. BTEX compounds (benzene, toluene, ethylbenzene, and xylenes) were analyzed using headspace analysis and gas chromatography/mass spectrometry (GC/MS) adapted from U.S. EPA Method 8260B-4. In this method, 10 g of soil was weighed and sealed in a amber vial and heated at 60 °C in an agitated water bath (Blue M MW-1120A-1 Magni-Whirl Bath, Illinois) for 4 h. The headspace samples were taken through septa using a gastight syringe and immediately manually injected into the GC/MS. Chromatographic separations were conducted using an Agilent (CA) model 6890 series GC equipped with a split/splitless injection port and electronic pressure control. All the compounds were separated on a HP-5-MS 30 m × 0.25 mm I.D. capillary column with a 0.25 μm 5% phenyl-dimethylsiloxane phase. The injector in the split mode was 280 °C and the injection volume was 100 μL. The oven temperature was initially 40 °C and then ramped at 4 °C/min to 50 °C, 8 °C/min to 120 °C, and 70 °C/min to 280 °C (and held for 5 min). The carrier gas was helium at a constant flow of 1.0 mL/min. Detection was achieved with an Agilent G5973N mass selective detector (MSD). Data were acquired using the Agilent Chemstation software (Agilent, CA). Selected ion monitoring mode (SIM) was used for sample analysis. The method detection limit (MDL) and limit of quantitation for each study compound measured by headspace analysis were 5 and 13 μg/kg, respectively. Recoveries for BTEX compounds ranged from 72 to 136%, with a median of 110%.

Pesticides by Organic Extraction. A organic extraction/GC/MS method was utilized to analyze semivolatile pesticides (acetochlor, alachlor, aldrin, atrazine, chlordane (α), chlordane (γ), diazinon, dieldrin, dyfonate, endrin, heptachlor, heptachlor epoxide, methoxychlofilr, metolachlor, nonachlor (cis), nonachlor (trans), prometon, and simazine). In the method, 10 g of a sediment were placed in a small vial to which 10 mL of a 50:50 (v:v) mixture of dichloromethane and hexane and 200 μg/kg of internal standard was added. The soil samples were manually agitated and then placed in an ultrasonic bath (Fisher Scientific model FS9) for 10 min. Next, the vials were agitated in a water bath at 60 °C for 2 h. The slurry was then centrifuged for 5 min at 9000 rpm and decanted into a second centrifuge tube. The decant containing the compounds and the internal standard were then taken to dryness at 10 °C under a nitrogen stream using a TurboVap (Zymark, MA). Finally, the dry samples were reconstituted with 1 mL of methanol and vortexed for 5 s prior to analysis by GC/MS using the same type of column as for BTEX analysis. The injector in the splitless mode was set at 280 °C, and the injection volume was 2 μL. The oven temperature was programmed to start at 100 °C, and ramped at 40 °C/min to 170 °C, 3 °C/min to 185 °C, 10 °C/min to 220 °C, and 60 °C/min to 280 °C (and held for 10 min). Selected ion monitoring mode (SIM) was used for sample analysis. Method detection limits (MDL) for each study compound ranged from 10 to 50 μg/kg for all compounds except acetochlor, for which the MDL was 75 μg/kg. Recoveries for all 21 pesticides were determined to range from 57 to 123%, with a median of 87%.

Leachable Metals by ICP/MS. A batch leaching method was employed to determine the leaching of pollutants from soil under simulated acid rain conditions. The procedure was based on EPA Method 1312, with slight modifications. In the procedure, 5 g of sediment was added to 100 mL of a 4.2 pH sulfuric/nitric acid mixture in a 125 mL polypropylene bottle that was then shaken at 180 oscillations/min for 24 h using an EBERBACH 6010 shaker. The mixture was then centrifuged using a ThermoForma high-performance centrifuge at 8500 rpm, and the supernatant filtered with a 0.45 μm Whatman PVDF syringe filter. The filtrate was then acidified with trace metal grade nitric acid (Fisher Scientific, Pittsburgh, PA) and analyzed for As, Cd, Cr, Cu, Pb, and V by the following the guideline of EPA Method 200.8 using an Elan DRC-e inductively coupled plasma/mass spectrometer (ICP/MS; Perkin-Elmer SCIEX, Concord, Ontario, Canada). Hg was analyzed using a Tekran 2600 ultra-trace level mercury analyzer according to EPA Method 1631. Method detection limits (MDL) for As, Cd, Cr, Cu, Pb, V, and Hg were 0.18, 0.059, 0.595, 0.356, 0.066, 0.141, and 0.002 μg/L, respectively. Spike recoveries for all seven metals were determined to range from 98.2 to 128.0%, with a median of 108.5%.

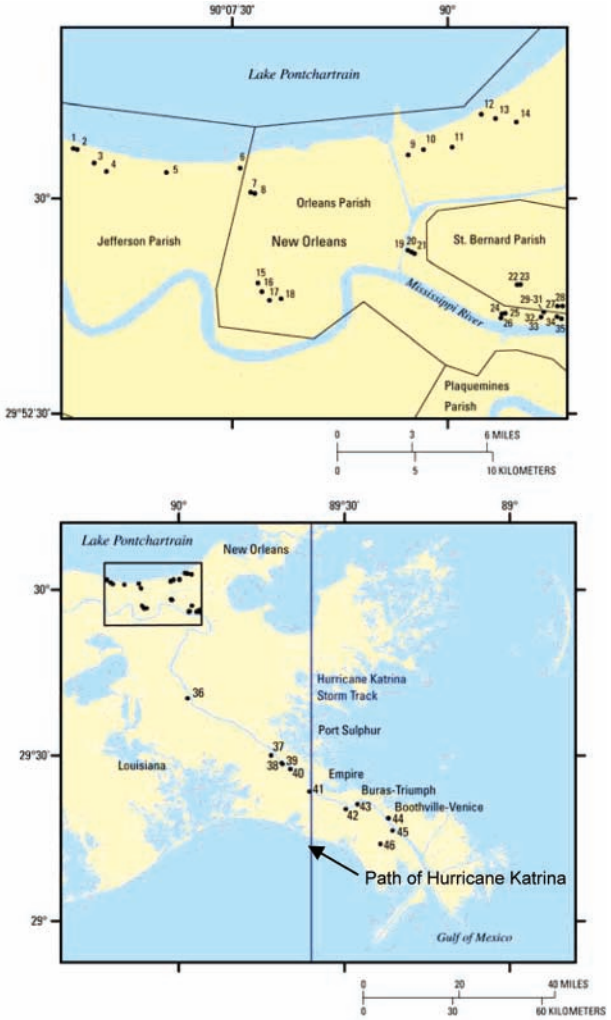

FIGURE 3. Locations of sediment samples from New Orleans (including Jefferson Parish, New Orleans Parish, and St. Bernard Parish) (top) and the Louisiana peninsula (bottom) that were analyzed for this study.

Results

Inorganic Contaminants. As, Cd, Cr, Cu, Hg, Pb, and V were all observed in the 44 soil and sediment leachate samples analyzed with median concentrations of 10, <0.5, 9, 11, <0.5, 7, and 11 μg/L, respectively, and maximum concentrations of 294, 0.9, 177, 52, 0.4, 72, and 229 μg/L, respectively (Figure 3, Table 1). Approximately 30% of samples had Pb concentrations equal to or greater than the 15 μg/L drinking water action level, and approximately 50% of the leachate samples had arsenic concentrations equal to or greater than the 10 μg/L drinking water maximum contaminant level (MCL). However, no sample concentrations exceeded the toxicity characteristic leaching procedure (TCLP) regulatory reference

TABLE 1. Results of Metals Analysis for Sediment Samples Collected in New Orleans and the Louisiana Peninsula[a]

site	latitude	longitude	leachable metal (μg/L)						
			As MDL= 0.18	Cd MDL= 0.06	Cr MDL= 0.60	Cu MDL= 0.36	Pb MDL= 0.07	V MDL= 0.14	Hg MDL= 0.002
1	30.02936	−90.21708	7.71	0.16	12.02	13.67	5.80	14.96	0.015
2	30.02936	−90.21708	20.06	0.37	40.18	17.90	17.80	86.30	0.049
3	30.02072	−90.20486	3.64	0.09	3.95	7.49	20.86	6.10	0.022
4	30.01617	−90.19808	17.70	0.23	39.59	25.99	17.21	76.51	0.054
5	30.01528	−90.16311	20.38	0.31	12.80	18.75	28.44	24.42	0.077
6	30.017819	−90.12039	2.27	N.D.	3.74	7.05	3.01	3.53	0.009
7	30.00392	−90.11400	13.62	0.92	1.75	11.52	2.92	2.44	0.003
8	30.00392	−90.11400	6.10	N.D.	4.05	4.69	0.63	1.51	0.007
9	30.02558	−90.02314	8.84	N.D.	8.80	11.33	0.81	3.88	0.004
10	30.02858	−90.01414	28.21	0.07	10.47	12.53	0.76	3.03	0.017
11	30.03011	−89.99758	6.79	0.44	9.60	12.34	16.49	27.03	0.120
12	30.04906	−89.98042	4.99	0.09	6.61	6.07	4.65	8.50	
13	30.04664	−89.97233	5.65	0.13	4.38	7.24	10.51	8.62	0.026
14	30.04461	−89.96014	4.33	0.08	5.04	7.74	4.81	7.99	0.010
15	29.95125	−90.11003	60.08	0.14	11.27	11.45	26.15	29.14	0.015
16	29.94629	−90.10763	293.58	0.35	31.79	50.28	71.77	32.97	0.320
17	29.94123	−90.10339	7.14	0.29	17.44	21.02	60.14	41.35	0.078
18	29.94235	−90.09671	28.31	0.18	19.30	20.44	61.54	38.74	0.059
19	29.97014	−90.02289	5.92	N.D.	4.67	11.24	1.28	5.28	0.007
20	29.96911	−90.02106	14.30	0.21	177.13	17.12	44.76	40.46	0.022
21	29.96858	−90.01967	3.17	N.D.	2.93	8.24	0.28	4.83	0.393
22	29.95058	−89.95986	14.92	0.12	5.77	9.18	18.73	7.19	0.016
23	29.95058	−89.95986	30.28	0.34	99.01	44.22	29.66	229.19	0.189
24	29.93364	−89.96783	44.43	0.19	9.79	8.08	7.53	18.09	0.023
25	29.93364	−89.96783	21.58	0.08	3.68	7.85	8.72	4.68	0.013
26	29.93133	−89.96889	18.48	0.11	3.83	10.47	7.21	10.66	0.007
27	29.93800	−89.93558	33.15	0.31	67.42	51.94	29.93	133.65	0.068
28	29.93800	−89.93558	33.45	0.19	28.13	14.86	16.12	64.97	0.044
29	29.93414	−89.94444	7.35	0.07	14.12	9.86	1.92	13.55	
30	29.93414	−89.94444	---[b]	---[b]	---[b]	---[b]	---[b]	---[b]	---[b]
31	29.93414	−89.94444	9.73	0.21	21.74	28.32	12.32	41.75	0.072
32	29.93139	−89.94589	9.99	0.07	11.28	9.81	1.49	11.15	0.078
33	29.93139	−89.94589	33.27	0.05	14.89	8.06	1.76	8.01	0.034
34	29.93164	−89.93672	13.27	0.06	5.42	9.43	3.79	11.31	0.035
35	29.93164	−89.93672	---[b]	---[b]	---[b]	---[b]	---[b]	---[b]	---[b]
36	29.67031	−89.97228	8.78	0.19	23.66	12.74	7.39	48.95	0.016
37	29.50036	−89.72013	19.18	0.09	4.56	31.43	0.76	5.56	---[b]
38	29.47453	-89.68794	2.94	0.07	1.54	4.86	0.32	2.56	N.D.
39	29.47217	−89.68544	16.77	0.12	9.50	30.69	18.64	17.46	---[b]
40	29.45642	−89.66294	4.14	0.06	6.82	6.82	0.90	2.32	0.007
41	29.38832	−89.60504	8.89	N.D.	7.90	10.04	1.38	5.56	---[b]
42	29.33595	−89.49522	6.08	0.09	13.71	13.24	4.88	25.08	0.012
43	29.35081	−89.45961	2.86	N.D.	6.00	7.85	0.39	1.83	0.108
44	29.30897	−89.36636	21.51	N.D.	3.33	12.72	1.32	4.52	0.006
45	29.27131	−89.35386	6.28	0.10	7.38	10.62	7.83	6.61	0.026
46	29.23153	−89.39014	7.65	0.13	4.30	21.48	0.37	10.03	0.009
mean			21.31	0.19	18.21	15.42	13.27	26.19	0.054
median			9.86	0.13	9.15	11.39	6.50	10.34	0.023
max			293.58	0.92	177.13	51.94	71.77	229.19	0.393
min			2.27	0.05	1.54	4.69	0.28	1.51	0.003

[a] N.D. = Nondetectable. [b] --- = No data.

level of 5000 μg/L for both As and Pb (U.S. EPA, 2005). This reference level evaluates metal mobility for landfills under worst case scenarios. In general, the TCLP method usually results in higher concentrations than the SPLP method used in this studies (except of As) (*11*). The leachable metal concentration data are consistent with the total metal concentration results for the same area reported by Cobb et al., which indicated that arsenic and lead concentrations in soil samples exceed U.S. EPA soil screening criteria throughout the city (*9*).

The highest leachable concentrations of Pb in sediment, which were observed in the Broadmoor District in Orleans Parish (Site 16, Figure 3, Table 1), ranged up to 72 μg/L. The highest arsenic concentration of 294 μg/L was observed for the same site.

Leachable Pb concentrations were generally low on the Louisiana peninsula, south of New Orleans, with only a single sample exceeding 15 μg/L in the leachate. Leachable As concentrations followed a pattern similar to that of Pb (Figure 3, Table 1). These results suggest that the leachable As and Pb could be a significant issue in the impacted areas of New Orleans, but probably not on the Louisiana peninsula. The leaching of metals from the samples, other than Pb and As, was not significant.

Finally, leachable mercury (Hg) concentrations were relatively low in the samples analyzed. Specifically. the maximum and median leachable Hg concentrations were 0.39 and 0.022 μg/L, respectively.

Pesticide Contaminants. Of the 18 pesticides analyzed, 16 pesticides were detected at at least one location (see the Supporting Information, Table 1). Most of the concentrations of the 18 pesticides analyzed were in the nondetectable range or at trace levels (see the Supporting Information, Table 1). In a majority of soil and sediment samples, the median concentration was non-detectable (ND), except for METH, which had a median of 133 μg/kg. METH was observed in sediments throughout each of the parishes in New Orleans as well as on the Louisiana peninsula (Figure 3, Table 2). For the triazines, ATZ, PROM, and SIM, a majority of the detections (sites 29−33; Figure 3) were all in the same neighborhood on the same street in St. Bernard Parish. Only a few other detections of these compounds were observed of ATZ, PROM, or SIM in the city or on the peninsula.

These data suggest that localized pesticide concentrations may be present, but that general contamination with pesticides does not appear to have occurred. Additional study of the pesticides in sediments, especially in residential neighborhoods, may be warranted. Pesticide concentrations were generally significantly below health guidelines by the World Health Organization (WHO) (based on tolerable daily intakes), or the U.S. Environmental Protection Agency screening criteria for residential areas. These data do not suggest widespread contamination by pesticides of either New Orleans or the Louisiana peninsula.

BTEX Contaminants. BTEX concentrations were generally very low in all samples tested. No toluene, ethylbenzene, or xylenes were detected above the MDL. Benzene was observed in 78% of the samples, but only very near the MDL of 10 μg/kg of soil. These data do not suggest widespread contamination by BTEX gasoline compounds of either New Orleans or the Louisiana peninsula.

Discussion

Levy breaches, precipitated by Hurricane Katrina and the associated storm surge, caused heavy sediment deposition in New Orleans and along the peninsula where the eye of the hurricane itself passed. A key concern was how contaminated were the sediments that now cover large sections of the city and peninsula. Normal human contact with sediments (and the contaminants therein) come through many different exposure routes, such as children playing in their yards, participation sports such as football and baseball, and gardening activities. The massive cleanup efforts in New Orleans continue to expose workers and citizens to sediments deposited in houses, yards, and streets. Inhalation of airborne particulates and dust can also be a significant exposure route to toxins in sediment particles.

Sediments deposited during the flooding of New Orleans were highly variable in depth. About 1.41×10^8 m^2 of New Orleans were covered by water and most all of this area was affected by some level of sediment deposition. Sediment at the site of the levee breaks consisted of thick (0.5−2.0 m) deposits of sand and gravel. This seemed to be the norm where flood flow velocities were large, but small enough to allow deposition of the sand fraction. In areas farther away from the levee break where water became still, silts and clays deposited. Observation during the data collection effort showed evidence of variable deposition rates as the water pooled and receded (Figure 2). Cars, boats, and other stationary items characterized the sediment deposition rates. Although it is difficult to place a number on the actual rate of deposition, and it becomes meaningless for this analysis, it is worth noting that the majority of silt-sediment fraction deposited very fast after the water pooled in New Orleans. Our calculations estimate that a total of 708 200 m^3 of sediment deposited throughout New Orleans' flooded area. This is on the basis of an estimated average sediment depth of 0.5 cm. Because of the level of destruction that occurred along the Louisiana Peninsula and the highly variable disposition of sediments within the levee system, it is impossible to estimate the quantity of sediment deposited in this area from outside the levee basin.

This study did not detect elevated levels of benzene or other gasoline constituents in New Orleans or the peninsula, even in sediment samples taken directly next to gasoline stations. These results are consistent with Pardue et al. that very low concentrations of volatile and semivolatile organic pollutants (gasoline components) were found in the floodwater shortly after Katrina (*3*). It should be noted, however, that this does not preclude the possibility that specific leaky underground storage tanks at other sites may well have caused localized contamination by BTEX compounds.

Concentrations of all of the pesticides analyzed were generally in the nondetectable range. For detections, generally trace concentrations in the soils and sediments were observed. These trace concentrations were generally orders-of-magnitude below WHO guidelines (on the basis of daily intake (e.g., *12−14*)) and priority screening levels for pesticides in residential soil by U.S. EPA (*15*, *16*).

In contrast to the BTEX and pesticides concentrations observed, the leachable metal concentrations (especially As and Pb) may pose a more significant health concern. The maximum amounts of leachable metals observed for As and Pb were 293 and 72 μg/L, respectively. These values compare with MCL for drinking water of 10 and 15 μg/L, respectively, with MCL goals of 0 μg/L for both (*16*). Thus, these levels could potentially pose a health issue if significant exposure occurred. Pardue et al. also reported that arsenic concentrations in all floodwater samples exceeded the drinking water MCL of 10 μg/L, and approximately 40% of samples have lead concentrations that exceed the drinking water action level of 15 ng/L (*3*). The MCL for Cr is 100 μg/L, which was exceeded in a single sample. The MCLs for Cd, Cu, and Hg are 5, 1300, and 2 μg/L, respectively, which are well above the observed values for leachable metals in the any samples analyzed. Pardue et al. also reported low concentrations of Cd, Cr, and Cu in floodwater samples (*3*). These results generate potential concern regarding As and Pb in sediments, especially in light of the fact that major fractions of these metals may remain bound to sediments through various complexation mechanisms with organics or inorganic fractions of the sediments. Further research is warranted that focuses on analysis of sediments in New Orleans to determine the presence of bound heavy metals that are not readily leachable.

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Supporting Information Available

Supporting Information Table 1 contains the results of organic chemical analysis for sediment samples collected in New Orleans and the Louisiana peninsula. This material is available free of charge via the Internet at http://pubs.acs.org.

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