

Microbial and Chemical Assessment of Regions within New Orleans, LA Impacted by Hurricane Katrina

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The city of New Orleans, LA was severely impacted by flooding and wind damage following landfall of Hurricane Katrina in August 2005. The city's drinking water infrastructure was severely compromised and massive amounts of sediment were redeposited throughout the flooded region. Thousands of homes were water-damaged resulting in the rapid growth of mold. In September and October 2005 a convenience sample of selected homes, tap water, surface water, and sediment within New Orleans was assessed for mold contamination, microbial contamination, and heavy metal concentrations. At selected sites, indoor mold spore concentrations were compared to outdoor concentrations. The purpose of this study was to conduct a baseline environmental assessment in an effort to identify public health threats caused by wind and flood damage. Surface waters contained high concentrations of bacterial indicators whereas no bacteria were detected in tap water, even from taps containing no chlorine residual. Sediment samples contained concentrations of lead and arsenic similar to pre-Katrina concentrations. Outdoor total spore (sp) concentrations ranged from >6500 to 84 713 sp/m³. Indoor concentrations ranged from 6142 to 735 123 sp/m³. For the 13 locations with matched indoor/outdoor samples, the mean indoor/outdoor spore ratio was 4.11 (ranging from 0.27 to >11.44). Inside 5 of the 13 homes, total spore counts/m³ exceeded 100 000, with measurements in the moldiest home exceeding 700 000 sp/m³. In conclusion, surface waters had high concentrations of bacterial contamination but no bacterial indicators were present in tap water. Sediment samples did not have appreciable increases in lead or arsenic. Flooded homes, however, contained substantial concentrations of mold which could present a public health exposure route to individuals repopulating and restoring the City of New Orleans.

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Introduction

On August 29, 2005 Hurricane Katrina, a category 3 storm on the Saffir–Simpson scale, slammed into the Gulf Coast of the United States with devastating impact. Thousands of square miles were declared federal disaster areas following severe wind and flood damage. In particular, the city of New Orleans, Louisiana was severely damaged when a series of earthen levees and flood walls failed, flooding a significant portion of the metropolitan area (1). Thousands of homes were under water for weeks while the floodwaters were pumped from the city. Following the landfall of Hurricane Katrina, there was considerable concern that environmental contaminants resulting from the stormwaters and flooding would cause increased morbidity and mortality during the protracted recovery, cleanup, and reentry of the Gulf Coast region (2). Of particular apprehension was the potential impact of exposure to microbial pathogens originating from human and animal waste, naturally occurring aquatic microbes such as *Vibrio*, mold present in water-damaged buildings, and metals such as lead and arsenic on residents, rescuers, and security personnel in the region around New Orleans, LA. In the days following landfall, editorials in numerous scientific journals and the lay press speculated on the magnitude of environmental contamination and human exposure (3–7).

Sporadic outbreaks of infectious disease were reported by the Centers for Disease Control and Prevention (CDC) in the Gulf Coast region following the hurricanes including an outbreak of norovirus in a Texas shelter, over 20 *Vibrio* infections in the region, and incidences of skin infections among rescue workers (8–10). Due to the magnitude of flooding and wind damage to roofs, extensive mold growth developed in damaged buildings resulting in concern about the potential for respiratory health effects from exposure to mold in water-damaged homes. It was determined that 46% of homes inspected in New Orleans had visible mold growth and that residents and remediation workers did not consistently use appropriate respiratory protection (4).

Human exposure to pathogenic microorganisms can result in an increased risk for infectious diseases. Microorganisms that persist in environmental media (water, soil, air, and fomites) following remediation, such as the dewatering of New Orleans, can cause continued exposure during reentry and reoccupation. Several federal agencies, including the Environmental Protection Agency (EPA), U.S. Geological Service (USGS), and National Oceanographic and Atmospheric Administration (NOAA), as well as independent nongovernmental research groups, collected environmental microbial and chemical samples in New Orleans and from the surrounding area impacted by Hurricane Katrina (1, 3). These data indicate high concentrations of bacterial contamination of water and sediment (1) and very high fungal concentrations in flooded homes in New Orleans (4). To date, however, there have been only a limited number of peer-reviewed publications that have begun to describe the potential environmental exposures faced by returning residents and reconstruction workers as New Orleans rebuilds and repopulates (11, 12).

As the magnitude of the damage began to emerge and evidence mounted that a lack of coordination and communication might preclude adequate public health assessments, members of the Johns Hopkins Bloomberg School of Public Health traveled to the Gulf Coast in September and October 2005 to conduct environmental assessments in an effort to identify public health threats. Water, air, and

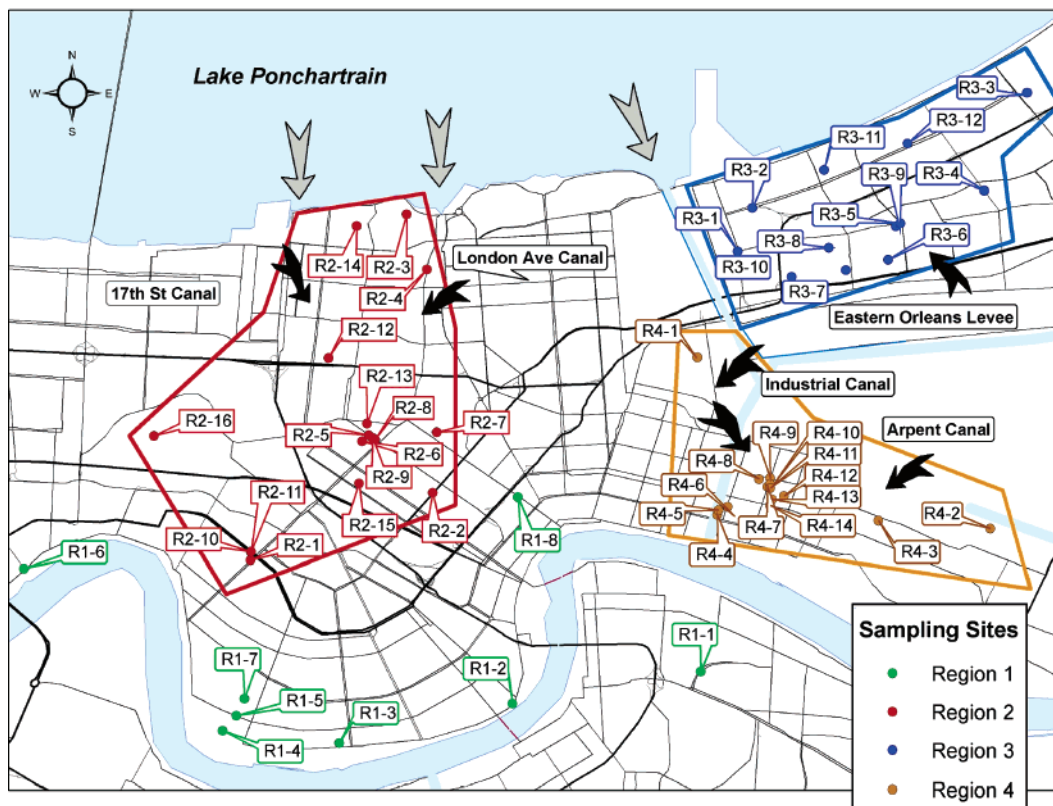


FIGURE 1. New Orleans sampling sites. Arrows represent levee breaches.

sediment samples were collected and analyzed for human indicator bacteria (enterococci, fecal coliforms, and *E. coli*), airborne mold, and metals (lead, and arsenic), respectively, as indicative of environmental contamination. Within New Orleans, sampling sites were identified based on empirical evaluations of the level of flooding and the availability of access. The results presented here provide a benchmark for microbial assessment of the New Orleans area following post-Katrina dewatering.

Experimental Section

Sample Site Selection in New Orleans. Sampling was conducted on September 16, 2005 and October 12–14, 2005. A priori identification of representative sampling locations within the City of New Orleans was not possible due to the considerable logistical complications involving access to the city, transportation within the city, and safety concerns. During the first sampling period, which was a single-day rapid assessment, initial samples of air, soil, and water were collected. A more intensive sampling campaign was conducted three weeks later when additional samples were collected throughout the city. Sites sampled in this study were categorized into four regions related to wind and water damage. Region 1 consisted of locations with wind damage but no flooding, Region 2 covered areas with both wind damage and flooding, primarily from the 17th St. Canal and Lincoln Ave. levee breaches, Region 3 covered areas with both wind damage and flooding, primarily from Eastern Orleans levee breach and gulf storm surge, and Region 4 covered areas with both wind damage and flooding, primarily from the Industrial Canal and Arpen Canal levee breaches and gulf storm surge (Figure 1 and Table 1). Samples were collected, stored, and transported using standard protocols relevant to the analyses to be performed.

Water Samples. For bacterial indicator analysis at each sample location, multiple 100 mL grab samples were collected in sterile Whirl-Pak Thio bags (Nasco Sampling Products, Ft.

Atkinson, WI) containing 10 mg of sodium thiosulfate to neutralize chlorine if present. Samples were stored on ice and shipped overnight to Johns Hopkins School of Public Health (JHSPH) for immediate analysis upon arrival. At tap water collection sites within homes, residual chlorine concentrations were determined by *N,N*-diethyl-*p*-phenylenediamine (DPC) analysis using a Hach DR/820 Colorimeter (Hach, Loveland, Co). Fecal coliforms, *E. coli*, and enterococci were enumerated from each water sample using standard membrane filtration methods (13). Briefly, 10-fold dilutions of each water sample were prepared (10^0 , 10^{-1} , 10^{-2} , and 10^{-3}) in 0.1% peptone buffer, and 10 mL of each dilution was filtered through 0.45 μm , 47 mm mixed cellulose ester filters (Millipore, Billerica, MA). Following filtration, the membranes were plated onto appropriate agar plates: mE agar was used for the detection and enumeration of *Enterococcus* spp.; mTEC agar was used for the detection of *E. coli*; and mFC agar was used for the detection of fecal coliforms (Becton Dickinson, Sparks, MD). Incubation conditions for the agar plates were as follows: mE plates, 41.5 °C for 48 h; mTEC plates, 35 °C for 2 h followed by 44.5 °C for 22 h; and mFC plates, 44.5 °C for 24 h. After 24 h, membrane filters from mTEC agar plates were placed in 1.2 mL of urea for 5 min, and bright yellow colonies were considered presumptive *E. coli*. Blue colonies arising on the mFC agar plates were considered presumptive fecal coliforms. After 48 h, membrane filters from mE agar plates were placed on esculin iron agar (EIA) plates and incubated at 41.5 °C for 20 min. Colonies characteristic of *Enterococcus* spp., ranging from pink to dark red on mE agar and producing a brown to black precipitate on EIA agar, were considered presumptive *Enterococcus* spp. (13). All resulting colonies were counted, and concentrations of fecal coliforms, *E. coli*, and *Enterococcus* per 100 mL of water were determined from dilution plates containing 30–300 CFUs using back-calculations.

Airborne Mold. On October 13 and 14 samples of airborne mold spores were collected at 13 matched indoor and outdoor

TABLE 1. Locations of Sites Sampled in This Study

ID	street	latitude	longitude
R1-1	Wall Blvd.	29.932514201	-90.029372121
R1-2	Tchoupitoulas St.	29.925890635	-90.067885476
R1-3	Cadiz St.	29.917842517	-90.103342417
R1-4	Calhoun St. (in/out) ^a	29.920375901	-90.127213332
R1-5	Magazine St.	29.923434551	-90.124399620
R1-6	Central Ave.	29.953539367	-90.167835946
R1-7	Perrier St.	29.926921050	-90.122715789
R1-8	Esplanade Ave.	29.968161317	-90.066777016
R2-1	S. Carrollton Ave.	29.955276230	-90.121474735
R2-2	N. Broad St.	29.968997459	-90.084203924
R2-3	Rail St. and Lakeshore Dr.	30.026135962	-90.089535932
R2-4	Wisner Blvd.	30.014827098	-90.085401232
R2-5	Orleans Ave. (in/out)	29.980816874	-90.097299623
R2-6	N. Solomon St. (in/out)	29.979576725	-90.098654325
R2-7	Fortin St. (in/out)	29.981452967	-90.083369087
R2-8	Orleans Ave. (in/out)	29.979937705	-90.096008997
R2-9	Solomon Pl. (in/out)	29.980281922	-90.096494216
R2-10	S. Claiborne Ave. (in/out)	29.957001838	-90.121437083
R2-11	S. Claiborne Ave. (in/out)	29.956958624	-90.121382880
R2-12	General Diaz St. (in/out)	29.996620673	-90.105541083
R2-13	Dumaine St. and W. Moss St.	29.983223970	-90.097679976
R2-14	17th St. Canal	29.925744790	-90.023042667
R2-15	Palmyra St. (in/out)	29.970969441	-90.099272723
R2-16	Rosewood Dr. (in/out)	29.980711075	-90.141210738
R3-1	Downman Rd.	30.018533762	-90.021862867
R3-2	Morrison Rd.	30.027447636	-90.018825452
R3-3	Strathmore Dr.	30.050899456	-89.962736177
R3-4	Reade St.	30.030891108	-89.971381831
R3-5	Dwyer Rd. and Galahad Dr.	30.024264748	-89.988565478
R3-6	Dotd Rd.	30.016827765	-89.991056579
R3-7	Ransom Rd.	30.014656107	-89.999719928
R3-8	Pecan Rd.	30.019245478	-90.003177556
R3-9	Dwyer Rd. and Charles Canal	30.023677456	-89.989475380
R3-10	Reynes St.	30.013321522	-90.010814401
R3-11	Dogwood Rd.	30.035083923	-90.004181522
R3-12	Brevard Ave.	30.040530111	-89.987110193
R4-1	Alvar St.	29.996775272	-90.030057947
R4-2	Squadron Rd. (in/out)	29.961664039	-89.970199983
R4-3	Genet St. (in/out)	29.963367241	-89.993094313
R4-4	Marais St.	29.964489000	-90.026036000
R4-5	Urquhart Rd.	29.965496431	-90.025742943
R4-6	Villere St.	29.966160278	-90.023904326
R4-7	Andry St.	29.970286223	-90.015768292
R4-8	N. Lizardi St.	29.971842463	-90.017471123
R4-9	Andry St.	29.972070451	-90.015171128
R4-10	N. Johnson St.	29.970809068	-90.015181187
R4-11	Choctaw St.	29.969962868	-90.015191059
R4-12	Lamanche St.	29.968315544	-90.012422795
R4-13	Flood St.	29.967680196	-90.014841068
R4-14	N. Claiborne St.	29.966428685	-90.015232782

^a Indoor sampling in addition to outdoor sampling done at these locations.

locations. Three additional outdoor locations were also monitored. Samples were collected using SKC VersaTrap spore samplers (SKC Incorporated, Eighty-Four, PA). Sampling was conducted at flow rates ranging between 10 and 15 L/min, corresponding to 50% cutpoints of 2.7–2.3 μm, respectively. Sampling was accomplished using linear piston vacuum pumps (Medo model, VPO435A Nitto Kohki, Hanover Park, IL) connected to power inverters which were attached to a car battery. Flow rates were calibrated before each sampling period using a primary standard, Bios DryCal DC-2M (Bios International Corporation, Butler, NJ). To prevent under- or overloading, sampling periods ranged between 10 and 17 min. Approximately 10% of samples were blanks for quality control purposes. Samplers were shipped overnight on ice to JHSPH, stored at 4 °C upon arrival, and then mailed to a PACB-certified laboratory for analysis of total spore concentration and individual mold type by direct microscopic spore morphology (AMA Analytical Services, Lanham, MD).

Surface Mold. Surface samples were collected indoors from 7 of the 13 homes discussed above. Samples were collected by vacuuming surfaces with open-faced 37 mm field sampling cassettes (VWR, Bridgeport, NJ) containing 37 mm Teflon membrane filters (Teflo, Pall Inc., Ann Arbor, MI) (14). Sampling was accomplished using Buck personal sampling pumps (model VSS-12, A.P. Buck, Inc., Orlando, FL) at a target flow rate of 4 L/min. In all homes sampling areas were selected where there was visible mold and adequate surface area for sample collection. Sampled areas ranged from 413 to 929 cm². Samples were analyzed for culturable molds using corn meal agar and malt extract agar by a commercial laboratory (P&K Microbiology, Cherry Hill, NJ).

Sediment/Soil Samples. Surface sediment/soil samples were collected from 36 outdoor locations and 6 indoor locations in New Orleans. Of the 36 outdoor locations, 4 samples were collected from Region 1, 7 samples were from Region 2, 14 samples were from Region 3, and 11 samples were from Region 4. Where floodwater deposition was observed, samples were collected from the entire deposition layer which varied in thickness between 15 and 20 cm. In regions where no flooding had occurred (Region 1), and in areas where no floodwater deposition was observed, samples were taken from the surface to approximately 6 cm into the ground. Samples were placed in 120 mL polypropylene wide-mouth bottles (VWR, Bridgeport, NJ), stored in a cooler, and shipped overnight to the laboratories at the JHSPH and stored at 4 °C until analyzed.

Samples were analyzed for lead (Pb) and arsenic (As) content by high-resolution graphite furnace atomic absorption (GFAA) spectroscopy (model AAAnalyst 600, Perkin-Elmer, Shelton CT). Samples were prepared by microwave digestion (model MARS5 XPress, CEM inc., Matthews, NC) using Optima grade nitric acid and hydrofluoric acid (Fisher Scientific, Columbia, MD). Ultrahigh purity water (Millipore, Billerica, MA) and Teflon digestion vessels (CEM, Matthews, NC) were used for all sample digestion processes.

Aliquots of all 42 sediment/soil samples were weighed in aluminum boats and heated at 120 °C overnight to dryness to determine the % weight due to water. Prior to digestion, an additional undried aliquot of each sample was coarsely crushed and weighed to 0.50 g ± 0.04 g using a microbalance (model T5, Mettler Toledo, Columbus, OH) in a CEM Teflon digestion vessel. For every ten samples, two standard reference material samples (NIST SRM 2709 San Joaquin soil, National Institute of Standards, Rockville, MD) were weighed and digested. Each sample was mixed with 9 mL of nitric acid and 3 mL of hydrofluoric acid. The vessels were allowed to sit uncapped for 15 min. The vessels were capped and assembled according to the microwave manufacturing protocol, then placed into the microwave digestion oven. Samples were irradiated using a one-step ramp-to-temperature method reaching a maximum temperature of 180 °C, and then filtered. The filtrate was diluted with ultrapure water to a final volume of 50 mL and 0.5% hydrofluoric acid strength.

A 5-point calibration curve was created at the beginning of each analysis. Standard calibration solutions for each element (10, 20, 30, 40, and 50 μg/L) were created from the highest concentration standard solution using the auto dilution feature of the auto sampler. A matrix modifier, a solution of Pd and Mg(NO₃)₂ (High Purity Standards, Charleston SC), was used for each sample to ensure that the element of interest remained in solution during the atomization phase of the furnace process. Method blanks were performed and demonstrated no contamination for these analytes from the instrument. When necessary, samples were diluted to ensure that the analyte concentration range fell within the range of the calibration curve.

TABLE 2. Summary Results for Water Samples Collected Within New Orleans, LA

location	type	Cl ₂ residual (mg/L)	fecal coliforms (cfu/100 mL)	Enterococci (cfu/100 mL)	E. coli (cfu/100 mL)
R1-4	tap	0.40	0	0	0
R2-1	surface	ND ^a	3.1 × 10 ⁵	5.2 × 10 ⁴	1.2 × 10 ⁶
R2-10	tap	0.05	0	0	0
R2-12	surface	ND	4.0 × 10 ²	4.0 × 10 ²	2.9 × 10 ²
R2-12	tap	0.24	0	0	0.0
R2-13	surface	ND	3.0 × 10 ²	1.7 × 10 ²	3.1 × 10 ²
R2-14	surface	ND	4.0 × 10 ¹	3.7 × 10 ²	1.9 × 10 ²
R2-15	tap	0.08	0	0	0
R2-2	surface	ND	5.7 × 10 ⁶	2.5 × 10 ⁴	3.0 × 10 ⁶
R2-3	surface	ND	1.0 × 10 ²	3.0 × 10 ¹	7.0 × 10 ¹
R2-4	surface	ND	3.0 × 10 ¹	2.0 × 10 ¹	2.0 × 10 ²
R2-5	tap	1.12	0	0	0
R2-6	tap	0.07	0	0	0
R2-7	tap	0.45	0	0	0
R2-8	tap	0.08	0	0	0
R2-9	tap	0.17	0	0	0
R2-9	surface	ND	2.5 × 10 ²	1.7 × 10 ²	3.2 × 10 ²
R3-2	surface	ND	3.9 × 10 ⁴	1.7 × 10 ⁴	2.1 × 10 ⁴
R3-5	surface	ND	4.6 × 10 ²	2.0 × 10 ²	7.3 × 10 ³
R3-9	surface	ND	2.3 × 10 ²	1.6 × 10 ²	6.7 × 10 ³
R4-1	surface	ND	2.4 × 10 ³	2.0 × 10 ²	ND

^a ND = not determined.

Results

Water Samples. Twelve surface water and nine tap water samples were collected, predominantly from Region 2 (Figure 1). All surface water samples contained bacterial indicators ranging from 20 to 5 × 10⁶ per 100 mL (Table 2). Four tap water samples collected from inside households in Region 2 had less than 0.1 mg/L free available chlorine with chlorine residual concentrations in the remaining 5 homes ranging from 0.17 to 1.12 mg/L (Table 2). None of the tap water samples contained bacterial indicators.

Airborne Mold. Analysis was conducted for concentrations of 23 genera of mold spores and total spore concentration (sp/m³). All samples for airborne mold were positive for at least one type of mold. All blank samples were negative. Of the 29 samples collected, 15 (9 outdoor and 6 indoor) were considered obscured due to overloading by either spores, particulate matter, or both. For obscured samples, the total spore count was defined as “greater than” the count reported. Outdoor total spore concentrations ranged from >6500 to 84 713 sp/m³. Indoor concentrations ranged from 6142 to 735 123 sp/m³. For the 13 locations with matched indoor/outdoor samples, an approximate ratio for indoor/outdoor total spore concentration was calculated based on the minimum total counts. On average the approximate indoor/outdoor ratio was 4.11 and ranged from 0.27 to >11.44. Table 3 reports spore concentrations (sp/m³) for those spores most commonly found and total spore concentration. *Apergillus/Penicillium* was detected in all indoor and outdoor samples, *Cladosporium* was found in all but one indoor sample. *Curvularia* was found in 21 of the 29 samples collected.

Surface Mold. Samples were analyzed for total area spore counts (sp/m²). Of the 7 samples collected 1 was considered obscured. Results are reported in Table 3. All surface mold samples were positive for mold spores with total spore concentrations ranging from 80 to 2.03 × 10⁷ sp/m². *Apergillus* was found in 5 of the 7 samples and accounted for 89–99% of the total spores detected. *Penicillium* was found in 6 of the 7 homes and accounted for 2–75% of the total spores detected. These results are in agreement with the air sample analysis.

Sediment/Soil Samples. All sediment/soil analyte concentrations were determined on a dry weight basis. Summary

statistics for sediment/soil concentrations of Pb and As by region are reported in Table 4. Method detection limits (MDL), as defined by three times the standard deviation of values reported for replicate measurements of the lowest calibration standard concentration (10 ppm), were 2.40 and 8.07 ppm for As and Pb, respectively. Percent recovery was determined for both analytes by analysis of the NIST SRM 2709 and found to be within 10% of reported values. Precision, estimated as the median percent difference of duplicate analyses, was 9% for As and 6% for Pb. Two As measurements (5%) fell below the As MDL. All measurements for Pb were greater than the Pb MDL. Measurements falling below the MDL were assigned a value half of the MDL for statistical purposes. Outdoor As concentrations did not differ between regions (single factor ANOVA $p = 0.7158$). However, outdoor Pb concentrations did differ by region (single factor ANOVA $p = 0.0036$). The highest Pb concentrations were found in Region 1 where the maximum concentration found was 453 ppm. The lowest level was found in Region 4, where the maximum concentration found was 90.2 ppm. As and Pb concentrations in soil samples collected indoors in Region 4 were not different from those collected outdoors (Student's t -test two tail $p = 0.67$ Pb; $p = 0.43$ As).

Discussion

Water Samples. The presence of high concentrations of bacterial indicators in surface water samples collected from flooded regions of the city were indicative of the large volumes of human waste that were present in the sewer system of a large metropolitan region. Interestingly, although four of the tap water samples contained very low concentrations of residual chlorine (>0.1 mg/L) none of the tap water samples contained bacterial indicators (Table 2) suggesting a low immediate bacterial risk associated with the drinking water. The massive amount of drinking water and wastewater infrastructure damage resulted in thousands of leaks throughout the distribution system. Maintenance of adequate water pressure and residual disinfectant concentrations was extremely difficult and in many areas of the city an absence of residents led to decreased water use. Pre-Katrina, the New Orleans Carrollton drinking water treatment plant normally yielded about 115 million gallons per day of finished water for the east bank of Orleans Parish. The Algiers drinking water treatment plant, which served the predominantly residential west bank portion of the parish, treated about 10 million gallons per day of water. The treated water at the two plants was pumped through more than 1610 miles of mains to more than 160,000 service connections. It was delivered to approximately 440,000 people on the east bank of Orleans Parish and approximately 57,000 people on the west bank (15). Following Katrina, it was estimated that roughly 85–100 million gallons of treated water were wasted each day through water pipe leaks created when trees uprooted during Katrina. That is more than four times the amount of water lost pre-Katrina, when the system—then considered antiquated—was leaking 20 million gallons every day (16). Due to the magnitude of leaks in the distribution system and continued renovation efforts, continued and enhanced vigilance of potable water quality is strongly recommended.

Sediment/Soil. Elevated Pb and As concentrations in soils are indicators of anthropogenic activities that often place communities at risk for hazardous environmental exposures. The presence of Pb and As in soil may be due to cumulative deposition over many years and may be unequally distributed across a community. The massive movement of water across the city raised the potential for a significant redistribution of soil contaminants throughout New Orleans. Mielke et al. have described soil lead concentrations in New Orleans from an extensive monitoring campaign conducted in the mid 1990s (17). As organized by census tract, they report widely

TABLE 3. Mold Concentrations Measured at Specific Locations within New Orleans, LA

location	<i>Cladosporium</i> (sp/m ³)		<i>Curvularia</i> (sp/m ³)		<i>Aspergillus/Penicillium</i> (sp/m ³)		total spore (airborne) (sp/m ³)		I/O ^f	total spore (surface) (sp/m ²)
	indoor	outdoor	indoor	outdoor	indoor	outdoor	indoor	outdoor		indoor
R1-2	NS ^d	2475	NS	18	NS	2849	NS	8814	NA ^g	NS
R1-4	267	2829	30	75	4205	13091	6308	24032	0.27	80
R2-3	NS	2644	NS	ND	NS	624	NS	>6500	NA	NS
R2-4	NS	3297	NS	1964	NS	8744	NS	17006	NA	NS
R2-5	6893	52051	293	7126	150771	7281	>162651	>69169	~2.35	2.03 × 10 ⁷
R2-6	615	6091	ND	79	454757	32512	467048	>40818	~11.44	NS
R2-7	1212	2226	ND	53	716	1620	6142	9384	0.61	NS
R2-8	2574	3644	ND	253	152150	11185	169310	19807	9.30	NS
R2-9	2241	2549	1494	439	17428	5010	26142	13272	2.19	93070
R2-10 ^a	1588	2894	99	114	68402	12983	>81904	>25662	~3.64	NS
R2-11 ^a	2025	2894	368	114	43621	12983	>75463	>25662	~2.90	NS
R2-12	ND ^e	418	ND	ND	734387	81575	735123	84713	8.81	NS
R2-15	3426	1470	ND	630	20706	32453	>31134	>70386	~0.53	77900
R2-16	927	1041	154	50	30655	1685	>37373	>6858	>7.13	94710
R4-2	708	1610	ND	64	86929	34186	102155	>42877	~2.41	400000
R4-3	1907	2105	58	1403	15485	5365	24266	>13126	~1.68	>205000
N	12	16	7	14	13	16				
geomean ^b	1479	2684	171	210	41324	8390				
se ^c	514	3110	195	505	216852	20662				
min	267	418	30	18	716	624				
max	6893	52051	1494	7126	734387	81575				

^a Same outdoor sample used for both locations R2-10 and R2-11. ^b geoman = geometric mean. ^c se = standard error. ^d NS = not sampled. ^e ND = not detected. ^f I/O = ratio of indoor to outdoor. ^g NA = not applicable.

TABLE 4. Summary Statistics for Pb and As Concentrations in Soil Samples Collected from Four Regions within New Orleans, LA; All Values Are in Units of μg/g

	Region 1	Region 2	Region 3	Region 4	
	outdoor	outdoor	outdoor	outdoor	indoor
N	4	7 ^a	14	11 ^a	6
Pb geomean	137	95.0	52.2	48.6	54.4
(se) ^b	(105)	(46.5)	(6.73)	(6.10)	(8.31)
min	39.4	26.5	36.5	28.0	34.5
max	453	292	120	102	90.2
As geomean	9.92	6.57	9.80	7.20	5.56
(se)	(1.01)	(4.15)	(1.23)	(1.12)	(1.68)
min	7.55	1.20 ^a	1.37	1.20 ^a	1.52
max	12.1	31.8	16.6	14.1	12.3

^a One As measurement below the MDL; value set to 0.5 MDL = 1.20. ^b Geomean (se) = geometric mean (standard error).

diverse soil Pb concentrations across the city with the highest concentrations, 600–1125 μg/g, found in an area similar to Region 1 of this study and the lowest concentrations, 0–200 μg/g, in areas similar to Regions 3 and 4. Although our sample collection was much more limited in scope, we also found the highest soil Pb concentrations in Region 1 and the lowest concentrations in Regions 3 and 4, suggesting that a massive redistribution of Pb did not result from the flooding. No samples were found to have a concentration greater than 1200 μg/g, the U.S. EPA standard for lead in bare soil outside of a children’s play area, although one sample from Region 1 exceeded the 400 μg/g, the average allowable for lead concentrations in areas where children play (18). Similar geographical data for As soil concentrations do not exist. The U.S. EPA Region 6 reports background soil As concentrations for Region 6, which includes Louisiana, to range from 1 to 17 μg/g (19). Across our study regions we did not find a statistically significant difference in soil As. In addition, only one sample reported an As concentration, 31.8 μg/g, outside of the background range. Again, this suggests that the flooding did not have a significant impact on soil concentrations and so did not cause a greater risk from these

contaminants to the public than was present before Katrina occurred.

Airborne and Surface Mold. Twelve of the 13 homes evaluated for airborne mold were located in either Region 2 or Region 4. One home was located in Region 1. Two of the 13 homes sampled did not show evidence of either flooding or water damage. Using water lines as indicators for the level of water intrusion, 4 homes were found to have suffered flooding to volumes ranging between 2 and 10 cm covering only the first floor of the residence or present only in the basement. Five homes showed evidence of flooding that ranged between 0.3 and 1.5 m of water. Two homes showed indications that they were inundated with over 5 m of water with one of the homes completely covered and the other having 1.5 m of water in the second story. Although there are no set criteria for determining the level of hazard due to the presence of mold in an indoor environment, Baxter et al. (20) provide guidance for judging the hazard presented by mold intrusion. The suggested airborne mold acceptance or rejection criteria for clean and moldy residential buildings were <1200 total spore counts/m³ and >1300 total spore counts/m³, respectively. Clean and moldy buildings were defined according to a specified set of criteria covering factors such as visible mold, visible water staining, a history of flooding or other water damage, and sewage damage. According to these criteria all homes in this study, including the homes that did not show evidence of flooding or water damage, would be considered “moldy” at the time of testing. On average, total mold concentrations were 4-fold higher indoors as compared to concentrations measured outside. Inside five of the 13 homes, total spore counts/m³ exceeded 100 000 sp/m³, with measurements in the moldiest home exceeding 700 000 sp/m³. This home, with all of its contents, had been closed since the hurricane. Four of the five high mold homes had the contents remaining in the home.

Area concentrations of surface mold are consistent with airborne mold results. The lowest area surface mold concentration, 80 sp/m², was found in a home which had no visible flood or water damage. The high surface concentration, 2.0 × 10⁷ sp/m², was found in the home with the second

highest airborne mold concentration. Although this home had been flooded with only 10 cm of water inside, this home had black mold covering most of the floors. At the time sampling was conducted in these homes, 6 weeks had passed since the storm. In the months since the hurricanes, homeowners have been returning to remediate or permanently vacate water-damaged homes potentially placing them at risk for dangerous mold exposures. The CDC report on mold prevention strategies and possible health effects (21) repeatedly stressed that individuals should minimize mold exposure that could result in adverse health effects by avoiding areas where mold contamination is obvious, using environmental controls and personal protective equipment while cleaning in areas contaminated with mold, and keeping hands, skin, and clothing clean and free from mold-contaminated dust (21). Given the magnitude of mold infestation many of these recommendations become very challenging but clearly are beneficial for maintaining public health.

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