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Mapping knowledge investments in the aftermath of Hurricane Katrina: a new approach for assessing regulatory agency responses to environmental disaster

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ABSTRACT

In the aftermath of large-scale disasters, the public's dependency on federal and state agencies for information about public safety and environmental risk is acute. While formal rules and procedures are in place to guide policy decisions in environmental risk assessment of spatially concentrated hazards such as regulated waste sites or vacant city lots, standard procedures for risk assessment seem potentially less well-suited for urban-scale disaster zones where environmental hazards may be widely dispersed and widely varying. In this paper we offer a new approach for the social assessment of regulatory science in response to large-scale disaster, illustrating our methodology through a socio-spatial analysis of the U.S. Environmental Protection Agency's (EPA) hazard assessment in New Orleans, Louisiana, following Hurricane Katrina in 2005. We find that the agency's commitment of epistemic resources or "knowledge investments" varied considerably across the flood-impacted portion of the city, concentrating in poorer and disproportionately African American neighborhoods previously known to be heavily contaminated. We address some of the study's social and policy implications, noting the multidimensionality and interactive nature of knowledge investments and the prospects for deepening and extending this approach through comparative research.

1. Introduction: into the neglected heart of science policy

In exploring the need for new policy tools to ensure that scientific research meet societal needs, Sarewitz and Pielke (2007:14) pose a simple question that reveals what they call the "neglected heart" of science policy: "How do we know if we are doing the right science?" Science funding is regularly justified on the grounds that scientists and science policy decision makers know what knowledge is needed for achieving broad societal goals such as public health or environmental quality; more of it is always presumed to be better than less. Yet Sarewitz and Pielke's question—and the silence that follows it—raises the possibility of a mismatch between the knowledge that science generates and the knowledge society needs. Drawing illustrative examples of such gaps from AIDS and climate change research, they observe that "very little consideration has been given to the types of information or knowledge that science policy decision-makers could call upon to improve the reconciliation" between the scientific supply of, and societal demand for, knowledge (p. 10). Their challenge to science policy scholars is to develop "use-

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inspired'' (Stokes, 1997) social science that aims to minimize inefficiencies in the societal uptake of scientific knowledge and information (Bozeman and Sarewitz, 2005) and to develop science policy mechanisms that lessen rather than deepen social conflict and inequality (Cozzens, 2007; Woodhouse and Sarewitz, 2007).

In this study we offer a new approach for the social assessment of regulatory science in disaster response toward that challenge. Inasmuch as environmental quality is an important societal goal, its assessment is derived largely from scientific knowledge and information produced by state and federal regulatory agencies. The public's dependency on regulatory agencies is acute particularly in the aftermath of disasters, where damage to the built and natural environments can be severe and widespread and where often the level of scientific uncertainty about the nature of consequent environmental risk is high. Formal rules and procedures are in place to guide policy decisions in environmental risk assessment of spatially concentrated hazards such as regulated waste sites or vacant city lots. Because they are known and available, standard procedures are also likely to shape regulatory responses to disasters. Yet unlike regulated waste sites, environmental risks in the aftermath of urban-scale catastrophe may be widely dispersed, widely varying, and distributed across a heterogeneous residential population. In those situations, it is exceedingly difficult to assess whether or to what extent standardized procedures for identifying risks best meet ''the priorities, needs and capabilities of the broadest group of constituents that could potentially make use of the resulting knowledge and information'' (Sarewitz and Pielke, 2007:9).

We examine how regulatory agencies work through this demand/supply problem using a socio-spatial analysis of the U.S. Environmental Protection Agency's (EPA) hazard assessment in New Orleans (Orleans Parish), Louisiana, following Hurricane Katrina in 2005. The storm, combined with catastrophic engineering failure of the federal hurricane levee protection system, drowned New Orleans with an estimated 114 billion gallons of salt water containing chemicals, metals, and biological pathogens creating a risk scenario of unknown proportions. With floodwaters covering 80% of New Orleans' land area and inundating the households of over 60% of its population (with some neighborhoods under water for up to six weeks) (Campanella, 2006), residents' need for block-level risk information—''is my home and neighborhood safe to live in?''—presumably was high and virtually uniform across the city.

As inscribed in internal planning documents, EPA's initial view of the public demand function was more limited geographically. The Agency's charge in the hurricane response project was ''to assess the presence of hazardous substances in residential sediments and the potential for exposure of residents to contaminants in sediments.''[1] In line with that institutional mission, the hazard assessment centered on flooded residential areas, largely ignoring parts of the city that did not flood as well as non-residential (i.e. industrial and commercial) areas within the flood zone.

In supplying knowledge to meet (perceived) public demand within targeted residential areas, the EPA led a year-long effort to characterize environmental hazards in the sediment and soil of flood-impacted Orleans, Jefferson, Plaquemines, and St. Bernard parishes.[2] Involving a dozen collaborating organizations, the disaster response was unprecedented in organizational scale and knowledge output, generating more than 400,000 chemical and biological analyses for the presence of up to 200 individual contaminants from approximately 1,800 sediment and soil samples across the four-parish region. Nine hundred fifty-two, or just over half, of those samples were collected in Orleans Parish. EPA used test data generated from those samples to determine whether contaminant levels in specific locations required further regulatory action.[3] Thus, while the scale and organization of the response was anything but business-as-usual, the process of identifying environmental hazards in flooded New Orleans does not seem to have been appreciably different from regulatory science conducted under more normal conditions and in relatively more contained environments (i.e. at regulated hazardous waste sites). Did this approach to disaster response meet residents' need for location-specific risk information?

One way to approach this question empirically is from the demand side, examining how knowledge needs among city residents differed across neighborhoods and changed over time. Unfortunately, this type of data does not exist and we are forced to assume, as EPA did, that citizen demand for knowledge was uniform within and limited to flooded residential areas. Another way to approach the problem is from the supply side, examining where and when EPA committed different combinations of available resources to the hazard assessment effort. This is the approach we take. By pairing EPA data with block-level demographic data from the 2000 U.S. Census, we investigate how the Agency's ''knowledge investments'' were allocated by race and household median income across New Orleans neighborhoods. Results of our analysis indicate that the type and distribution of knowledge investments committed to different neighborhoods vary widely, concentrating in areas that are populated disproportionately with African American and lower income residents. This and related findings do not entirely resolve the underlying normative issue of whether EPA's response should have been different. However, as we spell out below, our supply-side approach provides new insight into the social value of that response as reflected in the spatial, temporal, and epistemological distribution of location-specific knowledge. We address the social and public policy implications of this analysis and its normative limits in the discussion.

A better understanding of the social organization of knowledge production in this case is important for a number

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[1] EPA, ''Quality Assurance Sampling Plan,'' September 2005 (author's files).

[2] While a few university research teams and environmental organizations conducted additional small-scale sampling and testing independent of EPA, the EPA-led project we study was the sole state/federal regulatory response and the primary source of information on flood-generated environmental hazards guiding local and state regulatory, remediation, and public health policy since the storm.

[3] As completed, the project did not involve a full-blown risk assessment which would have included analysis of the bioavailability and exposure potential of contaminants.

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of reasons. First, while published assessments of the EPA project applaud its technical merits (Marris, 2006) and smaller independent studies seem to corroborate the EPA's general findings (Walsh et al., 2006), we know of no studies to date that systematically investigate how the hazard assessment research and sampling strategy was organized, or critically assess the potential impacts of that process. Doing so is important because knowledge generated by EPA continues to be a critical factor in shaping public policy and influencing residents' decisions on rebuilding as the city and region recover. Moreover, to the extent that the assessment provides a model for responses to future urban-scale disasters, as some have suggested (Walsh et al., 2006), it becomes all the more important to understand how closely scientific outcomes map onto societal needs and values.

Second, this analysis has implications for research on environmental inequality in the U.S. That literature is vast, and many of the studies contained in that body of research depend in one way or another on environmental regulatory agencies, particularly the EPA. Most national level studies of environmental inequality use EPA-produced data, while a handful of other studies assess questions of procedural and distributional inequity as the outcome of EPA policies and programs. For example, studies of ''environmental cleanup injustice'' have demonstrated that hazardous waste sites located in minority and low-income neighborhoods are less likely to be listed on EPA's National Priorities List (Superfund) (O'Neil, 2007). Other studies have examined the inequitable impacts of EPA policy enforcement (Cline and Davis, 2007) and the distribution of EPA penalties for environmental rule-breaking (Lynch et al., 2004). Even EPA's Environmental Justice Small Grants Program has been shown to have disproportionately limited impacts in the very communities the program was designed to serve (Vajjhala, 2007). The present study similarly speaks to the ways that regulatory science policy may unintentionally reinforce existing or create new forms of social and environmental inequality, which, in New Orleans, have long pre-dated Katrina's landfall (Pastor et al., 2006).

Finally, in addition to its clear policy relevance for New Orleans and beyond, the case presents a rare opportunity to gaze inside regulatory science conducted in response to disaster. Unlike most scientific work that takes place away from the public spotlight—in laboratories or distant field sites, for example—the intense public interest in and national significance of the government's hurricane response in New Orleans demanded levels of bureaucratic transparency that are unusual even within regulatory organizations that have an explicit mission in serving the public interest. This study capitalizes on the opportunity Katrina created to examine how complex organizations make, organize, and communicate scientific knowledge. We turn to that task now.

2. Disaster as prelude: what the Kat dragged in

Although media coverage of the flooding tended to focus on dramatic levee breeches in the middle-class and largely white Lakeview neighborhood and in the working-class and predominantly African American Lower Ninth Ward, detailed investigation shows that when Katrina's eye wall grazed the southeastern edge of the New Orleans metropolitan area on August 29, 2005, its storm surge triggered failures at scores of points along the hurricane protection levee system surrounding the city (Seed et al., 2006). At maximum flood, water covered well over 90 square miles in Orleans Parish (not including the undeveloped eastern marshes) and reached depths of 12 feet in certain hydrological sub-basins within the levee ''protection'' system—enough to completely submerge single-story homes (Campanella, 2006). As the storm surge receded into the Gulf of Mexico water levels inside the city dropped, reducing the flood footprint to about 60 square miles and stabilizing flood depths to one to two feet below earlier maximums. With temporary patches to the broken levees in place, pumps began dewatering the city. When Hurricane Rita made landfall on September 24, all but a few of the lowest lying neighborhoods had been drained. While the center of this second storm crossed into Louisiana some 200 miles west of New Orleans, the city's hastily repaired flood control system proved insufficient to prevent rising sea levels and rainfall from reflooding neighborhoods in the Lower Ninth Ward. Given these setbacks, it was not until mid-October—nearly six weeks after Katrina struck—that federal and state officials declared the city flood-free (Fig. 1).

Of course, salt water was not all that Katrina and Rita brought in to, or circulated within, New Orleans. Sediments and chemicals were two additional concerns. Both were suspended in the flood water and originated from a variety of sources. Most of the sediment left behind as the flood water receded was scoured from the bottoms of Lake Pontchartrain, Bayou Beinvenue, and from various manmade waterways and canals and pushed in to the city as the levees gave way. Sediment deposits of a few inches' depth blanketed flood-impacted neighborhoods and at certain levee breaches reached 1.8 m in height (Nelson and Leclair, 2006).[4] Some of the sediment introduced by Katrina came laced with chemical toxicants, but many other contaminants originated from within the city itself. Point sources of potential pollutants would include gas, oil change, auto service stations, laundries and dry cleaners, pest control companies, paint and hardware stores, hospitals, and cemeteries. Potential non-point sources included as many as 350,000 automobiles and other vehicles submerged in the flood as well as a wide variety of hazardous substances typically stored in homes, garages, and backyard sheds. Over time, these sediments and whatever toxicants adhered to them have been integrated into the soil, flushed down storm drains, blown through the air, trucked to landfills, and tracked by foot into residents' homes and workplaces. In the immediate aftermath of the storms, the potential risk from these as-yet largely unknown hazards fueled a precedent-setting effort by federal and state agencies to assess the damage and subsequent environmental risk.

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[4] As Nelson and Leclair note, 932,000 cubic feet of material was ejected from the London Avenue canal into the adjacent neighborhood—enough material to cover a football field to a depth of sixteen feet. Most, but not all of this material was sand from the Pine Island Formation, a Mesozoic-era barrier island chain.

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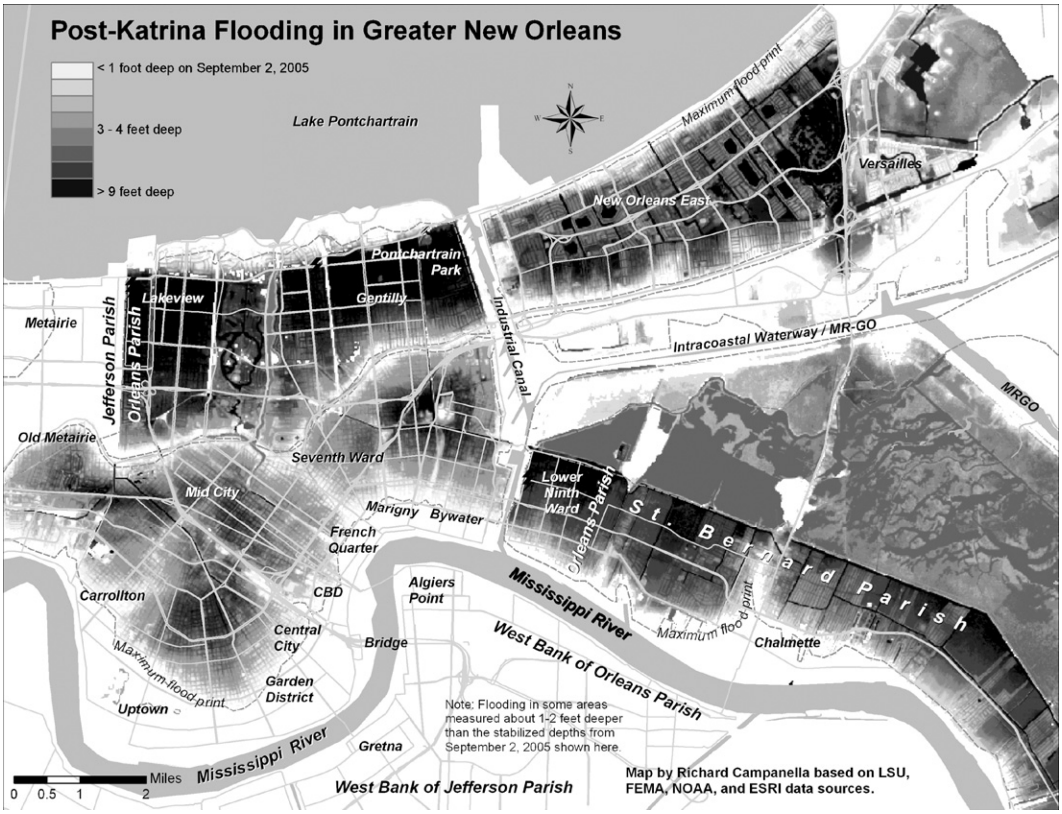

Fig. 1

3. EPA hazard assessment of Orleans Parish, Louisiana

As noted, EPA was given a formal mandate to identify environmental hazards in residential sections of flooded New Orleans and assess the exposure risks to returning residents. Work toward this goal began in early September 2005 and continued through August 2006. This section summarizes that year-long process.

3.1. *Primary and adaptive sampling strategies*[5]

Sample collection and chemical analysis in Orleans Parish generally proceeded in four time-delimited phases. Each of the primary sampling strategies was guided by distinct goals and approaches that were occasionally augmented by adaptive sampling strategies. Initial sampling began September 11 and ended October 14. The objective of sampling during ''Phase I'' was to assess the presence of hazardous substances in residential-area sediment and to assess whether those substances posed short-term exposure risks to residents and emergency workers. Sampling points were widely distributed with the goal of providing an objective characterization of sediment chemical content. Teams collected 239 sediment samples from 215 locations across the city.[6]

Sampling in Phase II ran from October 29 to November 6. Here the objective was to identify ''areas of concern'' where concentrations of hazardous materials could pose long-term exposure risks to returning residents.[7] Like Phase I, the strategy for collecting sediment samples in Phase II was systematized spatially along a grid, but was limited geographically to the devastated Lower Ninth Ward, where twenty-six sediment samples were collected from twenty-one unique locations.[8]

Phase III sampling efforts conducted during February 16–22, 2006, sought to characterize the spatial scope of contamination at thirty-two Orleans Parish locations where earlier testing had indicated high concentrations of one of three contaminants—arsenic, lead, or benzo(a)pyrene. At each of these thirty-two ''hot spots,'' collection teams used a subjective measure of the relative character of the neighborhood as largely residential or largely commercial to determine how many samples to take in each area. They identified 9–10

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[5] This terminology is ours, not EPA's. We make the distinction to provide analytical clarity. EPA began distinguishing ''phases'' of the assessment process in January, 2006, after sampling for what became phases I and II had already occurred and after city officials and environmental and community groups raised criticisms of the project.

[6] EPA quality assurance protocol calls for 10–20% sample duplication. Duplicate sampling accounts for differences between samples collected and sample locations. In this case, twenty-four duplicate samples were collected, representing 11% of total.

[7] EPA defines ''areas of concern'' as locations where lifetime cancer risk exceeds 1 in 10,000.

[8] The Lower Ninth Ward was an especially hard-hit neighborhood detached from the heart of Orleans Parish and sharing a hydrological sub-basin with neighboring St. Bernard Parish. Most of the testing in Phase II occurred in adjacent St. Bernard Parish.

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new sample locations in neighborhoods determined to be ''100% residential'', 6–8 in areas determined to be ''60% residential,'' and so on. In all, 256 samples were collected from 222 unique locations—each arrayed around one of the thirty-two previously identified hot spots.

Phase IV samples were collected between April 6 and May 6, 2006. Concentrated in neighborhoods lying downriver from the historic French Quarter, the main goal in this phase was to update the sediment analyses from Phases I and II. Our analysis shows that 444 samples were collected from 373 eastern New Orleans locations.[9]

In addition to these primary strategies for characterizing contaminants in flood sediment, EPA also pursued adaptive strategies within the general four-phase scheme that account for twelve percent of total samples collected. Sometimes adaptations in sampling and testing involved targeted responses to new information generated from earlier testing. For example, eleven sites were re-sampled during Phase II based on analysis of Phase I samples. More often, adaptive strategies seem to have developed as responses to ongoing public and/or Agency concern about the fate of contaminants at previously existing hazardous waste sites. For example, twenty-three soil samples collected during Phase I reflected Agency concerns about re-exposed contaminants near a remediated Superfund site formerly known as the Agriculture Street Landfill. In Phase III, the same site was the focus of additional soil and sediment sampling, as was a Seventh Ward neighborhood bisected by rail lines and highway interchanges, and an abandoned pesticide storage and mixing facility that had closed in the mid-1980s. And during Phase IV, public controversy surrounding the reopening of another former landfill is likely to have prompted the collection of additional soil samples at that site. While it is difficult to pinpoint the specific factors that propelled each adaptive strategy, collectively they attest to EPA's flexibility in responding to new and pre-existing information, as well as the Agency's sensitivity to public criticism in the course of a knowledge production process fraught with uncertainty and constrained by budget, time, and political pressures. Combined, the assessment project produced a total of 952 unique sampling points in Orleans parish. Each sample was analyzed for various subsets of chemicals, heavy metals, and biological pathogens.

3.2. *Chemical testing*

The suite of analytes used for the hazard assessment was developed by scientists at EPA in consultation with a scientific advisory board and researchers at the Centers for Disease Control and Prevention. Most of the analytical work was conducted by two private laboratories working under contract. For quality assurance, duplicate samples were split between the two labs and results compared.

While summary reports claiming that sampled materials were tested for ''200 substances'' may give readers the impression that testing was comprehensive, in fact, no single sample from Orleans parish was subjected to tests for all of the 200 *different* analytes.[10] There is rough correspondence between the number of analytes tested and sampling phase (see Table 1). For example, just as Phase I sampling covered the largest geographic area, so did analyses from those samples have the greatest epistemic reach, with each sample analyzed for the presence of approximately 195 different analytes. In Phase II forty percent of the samples taken from the Lower Ninth Ward were tested for 177 or fewer analytes (not indicated in Table 1), and samples collected during Phase IV received tests for approximately 128 analytes. Most anomalous are the Phase III soil samples which involved tests for just three analytes of specific concern, and in no case were all three tested in a single sample. Thus the data indicate a general decrease in the amount of knowledge produced per sample over time. In the next section we develop a framework for examining the spatial, temporal, and epistemological organization of these ''knowledge investments.''

4. Mapping knowledge investments

In this study, knowledge investments refer to the time, money, technologies, expertise and other resources that EPA expended in collecting soil and sediment samples, returning to sampling locations for follow-up sampling, and performing tests on the sampled material.[11] These activities were not evenly distributed across the flood zone. As noted above, more samples were collected in some areas than others; some areas received attention for longer periods of time than did others; and more tests were conducted on some samples than others. The empirical challenge is to develop aggregate measures that capture the distribution of EPA knowledge investments along three dimensions (spatial, temporal and epistemological).

The methodology we employ to address this challenge involves three steps, beginning with data from the 2000 U.S. Census. In keeping with the EPA's stated mission to assess contaminants *in the flood zone*, first we identify blocks in Orleans Parish falling within or overlapping with the flood perimeter ($n = 7{,}231$). These blocks also correspond to EPA's spatial array of sampling sites. By aggregating the number of people living in these blocks, we determined the pre-Katrina

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[9] The city of Chalmette in neighboring St. Bernard Parish was also included in Phase IV. Summary reports indicate that sample collection teams visited 1,676 randomly selected grid points and collected 712 sediment samples from 586 locations in both parishes, meaning that more than a thousand samples were *not* collected from grid points either because there was too little sediment (i.e. less than 0.5 cm) or the grid points lay in commercial/industrial areas. Test result data do not indicate where these visit points are located, nor do they indicate how many were in Orleans parish.

[10] Among the dozen or so samples with 200 total tests, certain analytes were tested multiple times.

[11] The knowledge investments we identify are not exhaustive. We know, for example, that some sites were visited, but no samples were collected (see note 7). Because such site visits leave no measurable trace in the database, we cannot include them in this analysis.

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Table 1 – Primary and adaptive sampling strategies, Orleans Parish, Louisiana.

Primary strategies	Phase I	Phase II	Phase III	Phase IV
		Dates		
	Sept. 11–Oct. 14	Oct. 29–Nov. 6	Feb. 16–22	April 6–May 6
Geographic scope	Citywide	Lower 9th Ward	32 "hot spots"; various locations	Eastern N.O.
Sample media	Sediment	Sediment	Soil	Sediment
Samples collected	239	26	256	444
Unique sampling pts	215	21	227	373
Unique analytes	194	194	3	128

Adaptive Strategies			Dates			
	Oct 1–2	Nov. 19–20	Feb 16–22	Feb 17	April 7	April 10–12
Geographic scope	Superfund site	Various locations	Superfund site & 7th Ward rail interchange	Abandoned pesticide facility	Reopened Landfill	Lower 9th Ward
Sample media	Soil	Sediment	Sediment	Soil	Soil	Sediment
Samples collected	74	15	53	10	11	20
Unique sampling pts	23	11	46	9	10	17
Unique analytes	2	171	128	21	70	193
% of Total Samples	2.42	1.16	4.83	0.95	1.05	1.79
Total samples collected: 1,148				Total unique sampling points: 952		

Source: EPA Hurricanes Katrina and Rita Response Project (http://oaspub.epa.gov/storetkp/dw_home). Notes: a. Differences between "Total samples collected" and "Unique sampling points" are duplicate samples collected for quality control. b. "Unique analytes" refer to specific compounds or elements that tests employed on a given set of samples were designed to identify.

flood zone population to be 359,470, or roughly 74.2% of the total parish population.[12]

Next we identify flooded blocks by racial composition (percent black) and by median household income (MHI). Race and MHI are key variables commonly used in statistical analyses designed to address questions of environmental inequality in U.S. metropolitan areas (e.g. Saha and Mohai, 2005; Downey, 2007). Because the flooded neighborhoods we observe in this study are almost entirely Black/White, the simple inclusion of "% Black" provides a relatively unambiguous account of the main omitted, reference category (White). Census data on race are reported at the block level, while MHI is reported at the block-group level.[13] Even at the courser block-group level, these measures provide substantially more specificity than most studies of environmental inequality, which are typically based on census-tract or county-level data. "Percent Black blocks" are measured as the proportion of African American residents broken out into quintiles. We also included a "zero population" category in this analysis to account for the fact that there were no people residing in nearly two thousand flooded blocks. Because income distributions in New Orleans are highly left-skewed, we are unable to use equal percentage increments for "MHI block groups" as we do for race. Had we done so, virtually all of our data would fall into a single category representing MHI ranging from $0 to 49,999. Instead, we use quintiles based on number of sampling points. There is no "zero population" category for income because, unlike the block-level data, none of the larger block-group units in this study were unpopulated in 2000.

Finally, we map EPA's knowledge investments using data from the EPA Hurricanes Katrina and Rita Response Project (available at http://www.epa.gov/katrina/index.html). This database contains parameters and results for every chemical and biological analysis conducted on every sample collected in the hurricane-impacted region under the Response Project. The present study includes data for all unique soil and sediment samples collected in Orleans Parish (N = 952) and the corresponding population of analyses conducted from those samples (N = 106,405).[14] By plotting the location of the 952 samples we are able to tabulate for each racial and income category the total number of sampling points, dates of first and last sample collection, and the total number of tests conducted on those samples. This strategy produces three related but conceptually distinct measures—*density, duration, and intensity*—of EPA's knowledge investments in its hazard assessment of New Orleans.

Density is calculated as the mean number of sampling points per block (or block group) and measures the geo-spatial distribution of knowledge investments across the flood zone. In the EPA assessment process, the presence or absence of

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[12] This figure likely overestimates the flood zone population by approximately seven percent, based on results of a citywide population estimate taken just before Katrina struck (US Census, 2005). While this numerical discrepancy has little bearing on the validity of our findings, given the far more accurate and spatially detailed nature of data from the decennial Census, which are derived from 100% population counts, we ask readers to keep these differences in mind while interpreting population totals in the appended tables.

[13] The 2000 Census characterizes block groups as contiguous clusters of blocks with populations of about 1,500 people.

[14] We did not include duplicate samples in Orleans parish that were collected for quality assurance purposes according to standard EPA protocol. One anomalous sample that spatial coordinates located in the middle of the Mississippi River was also dropped from the population of samples.

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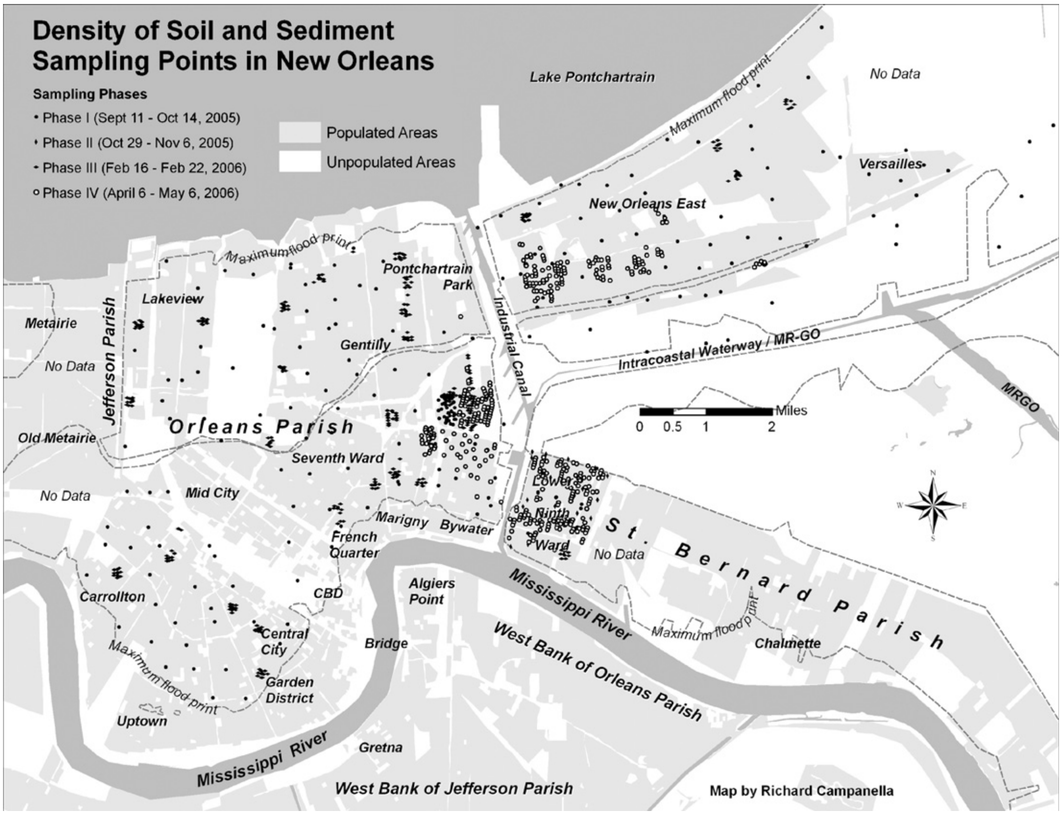

Fig. 2

contaminants in each sample is used to represent soil quality among a given number of blocks. In spatial terms, samples that are clustered close together offer greater knowledge potential than samples that are spread further apart. In our usage, density refers to the proportionate representation that samples provide to nearby blocks (and implicitly to people living on or returning to those blocks), as depicted in Fig. 2.

Duration is calculated as the mean number of days after Katrina that samples were collected. It measures the temporality of knowledge investments. Hazard assessment teams visited some areas repeatedly over the eleven-month sample collection period, while other areas were visited only once. Thus, as shown in Fig. 3, duration is an indicator of the relative distribution of institutional ''attention'' across flooded city neighborhoods.

Intensity is calculated as the mean number of tests conducted per sample and measures the relative amount of knowledge produced across the hazard assessment process. Like the spatial and temporal distribution of knowledge investments, the knowledge derived from each sample was also highly uneven, with the number of tests for the presence or absence of various contaminants ranging from 1 to 196 across the population of samples. We interpret intensity in terms of the amount of knowledge or ''epistemic depth'' achieved with each functionally equivalent soil or sediment sample (see Fig. 4).[15]

Density, duration, and intensity are conceptually distinct dimensions of knowledge investments. Density measures the distribution of sampling points around blocks. Duration measures the distribution of institutional attention around sampling points. And intensity measures the distribution of knowledge around soil and sediment samples. These measures are also related, in the sense that density and duration characterize the social organization of knowledge potential (i.e. when and where sampling occurred), while intensity characterizes the social organization of knowledge itself (i.e. the amount of testing). Analysis of these data follows.

5. Racial distribution of knowledge investments

The dominant racial pattern in the New Orleans Metropolitan Statistical Area is hypersegregation[16] and this is true of the flood zone as well: nearly sixty-five percent of flooded New Orleanians lived on blocks where African Americans accounted for at least eighty percent of the population, while thirteen percent lived on blocks where African Americans made up less than twenty percent. This means that

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[15] To be clear, intensity measures the amount of knowledge produced from equivalent investment units (i.e. tests); it does not measure the value of the resulting knowledge in terms of potential exposure or health risks.

[16] Demographers have used the term ''hypersegregation'' to describe metropolitan areas in which minority segregation ranks .6 or higher on at least four out of five measured dimensions (Massey and Denton, 1988, 1989). Black–white hypersegregation in metropolitan New Orleans was documented in 1990 (Massey, White, and Phua 1996) and in 2000 (Wilkes and Iceland, 2004).

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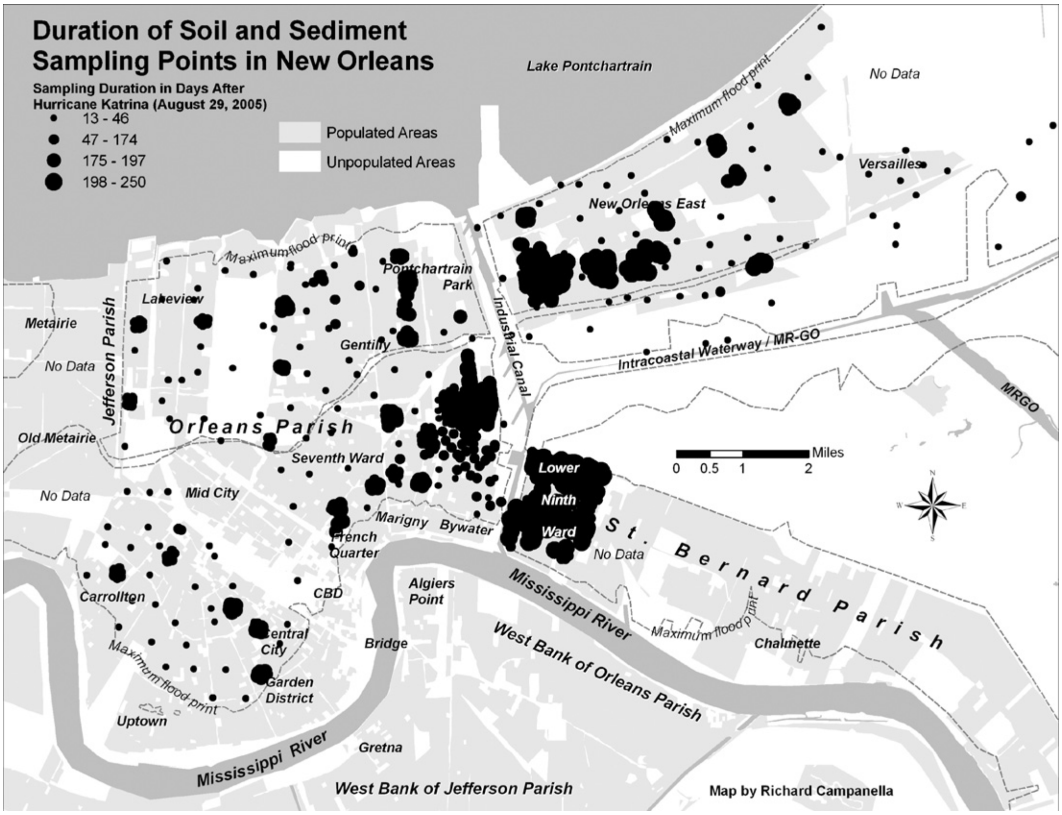

Fig. 3

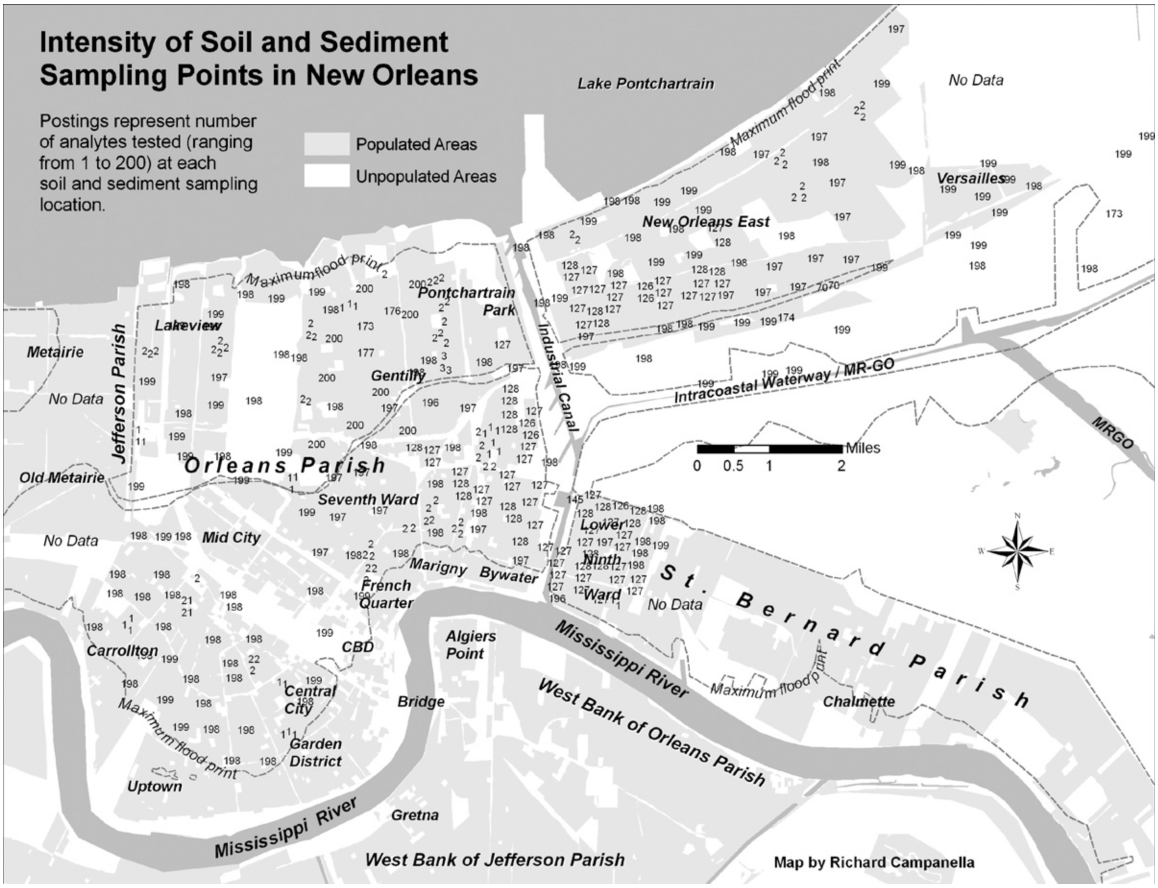

Fig. 4

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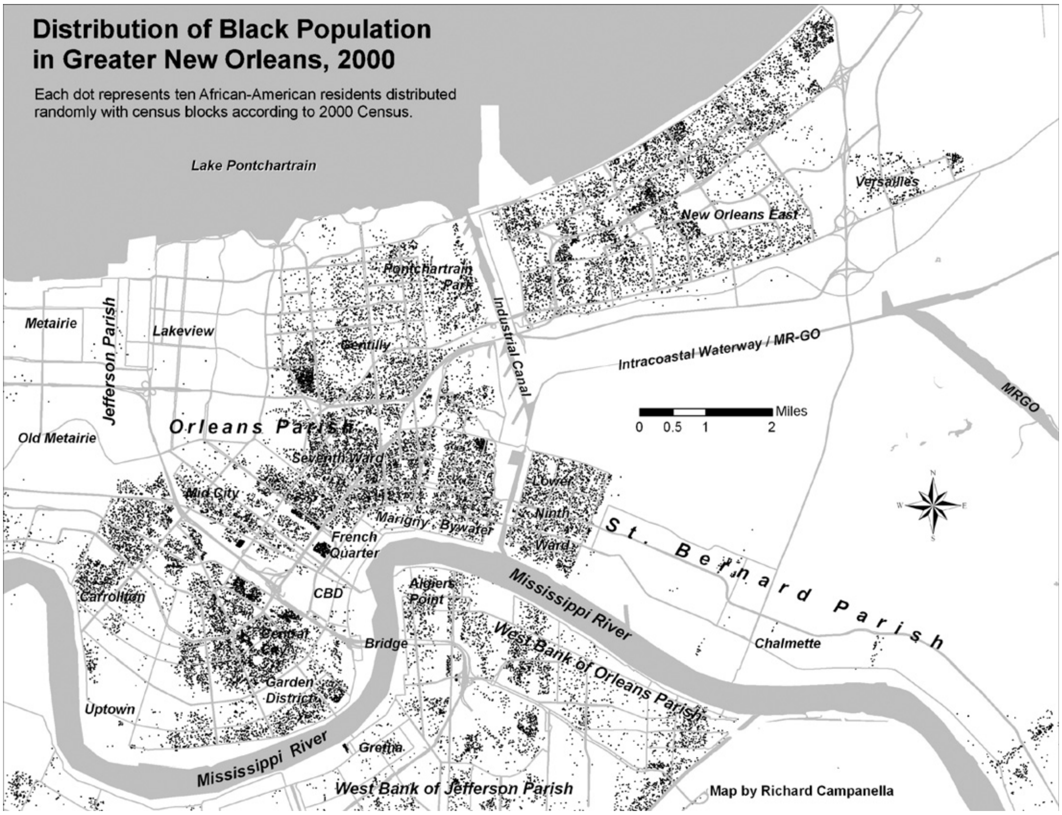

Fig. 5

hypersegregation—whether black or white—characterized nearly seventy-nine percent of flooded city blocks. By contrast, in only six percent of flooded blocks were residents living in racially integrated neighborhoods that were 40–60% African American.[17] However, neither the extreme levels of residential segregation nor the large proportion of the population living in highly segregated neighborhoods prior to Katrina's landfall mean that African American residents suffered disproportionate flooding. Prior research demonstrates that the racial composition of flood victims was roughly, though not perfectly, proportionate to the racial composition of the entire city (Campanella, 2007). These two demographic features—the flood zone's hypersegregation and proportional impacts of flooding—provide context for our analysis (Figs. 5 and 6).

Table 2 describes the racial distribution of knowledge investments measured in terms of density, duration, and intensity. The dominant pattern running across all three measures is that knowledge investments increase in rough proportion to the rising percentage of African American residents. Generally, sampling point densities become greater, sample duration increases, and testing intensity deepens among blocks where African American residents are a clear majority. Conversely, knowledge investments become lower, shorter, and shallower in blocks where African American residents are a clear minority. These trends are not uniform, however, and a closer examination of the data reveals two more specific patterns that are not as easily reconciled: knowledge investments are greatest where black segregation is highest and also where black and white residential patterns are most integrated.

Sampling points cluster most densely on blocks characterized by hypersegregation of black residents. These blocks represent 42% of the flooded population and contain 68% of the sampling points in our study. The knowledge potential is estimated by the number of blocks "represented" per sample point which, for these highly segregated blocks, is 4.7. Racially integrated blocks account for 4.9% of the flood zone and were the target of 4.7% of collected samples. Here, each sample represents 7.2 blocks. By contrast, blocks characterized by hypersegregation of white residents represent 14.7% of all flooded blocks but received just 7.8% of total samples. Each of these samples represents 14.1 blocks. Not only are blocks that are highly segregated white blocks disproportionately under-sampled, the knowledge potential generated by sampling in those neighborhoods is half that of racially integrated blocks and less than a quarter of the knowledge potential generated in blocks that are black hypersegregated. We find similar patterns in our measure of duration. Mean duration is also greatest in hypersegregated black blocks (160.4 days), followed closely by racially

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[17] These patterns are somewhat less pronounced in the flood zone than in the Parish as a whole: ≥80% Black blocks (30.2%). ≤20% Black blocks (45.8%), and 40–60% Black blocks (7.9%) U.S. Census (2000).

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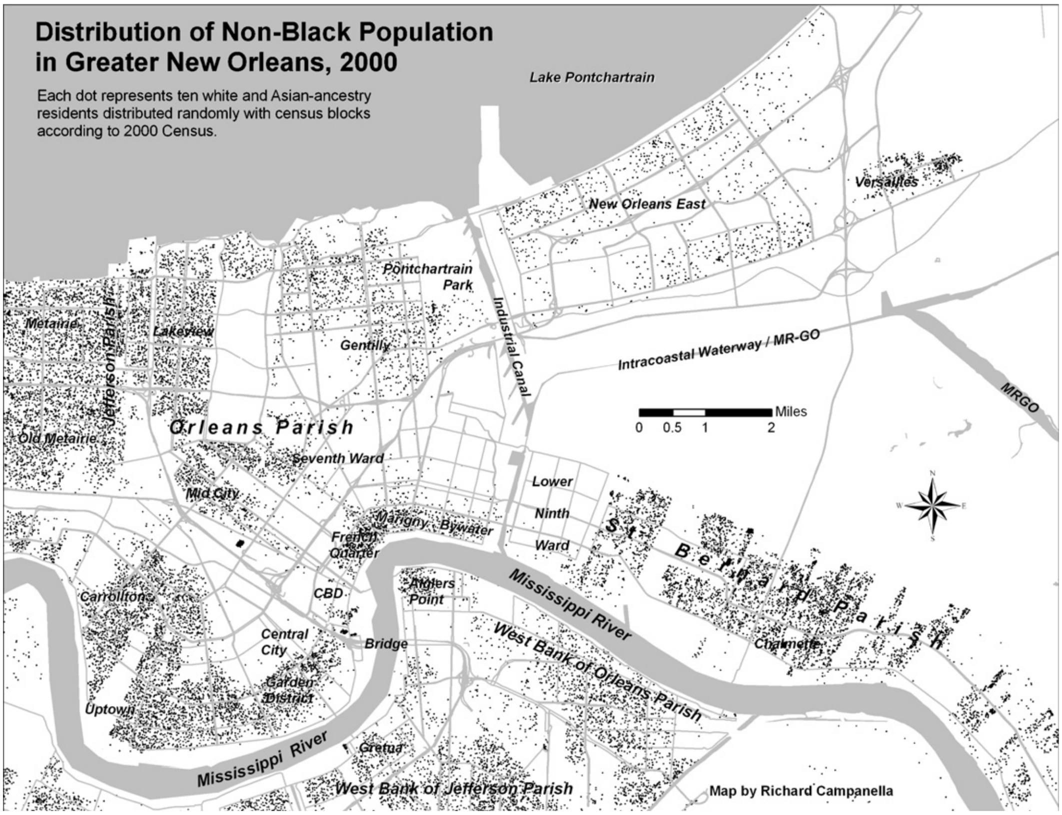

Fig. 6

integrated blocks (152.6 days), and is lowest in blocks that are predominantly white.

These data show that EPA's sampling efforts concentrated disproportionately in blocks with either overwhelmingly black or racially integrated populations. We note, however, that *within* these two block categories, the spatial patterning of samples (i.e. density) is also the most uneven. This is demonstrated by standard deviations for density that are on average more than twice that of the other block categories (.742 vs. .350). These differences in the size of standard deviations raise the possibility—explored in greater detail later in the paper—that particular blocks within these larger block categories account for the high density of sample points, suggesting that the environmental interests of most residents living on such blocks were not directly served by densely clustered sampling in demographically similar but geographically distinct areas.

Findings from our analysis of the intensity of knowledge investments provides similar support to our primary claim that investments are generally greater in flooded blocks where residential composition is predominantly African American. Just over 72% of all unique tests were conducted on sampled material taken from such blocks, with the vast majority again concentrated in hypersegregated black blocks (*n* = 72,740; 68.4%). Comparatively, flooded blocks in predominantly white areas received just 7.9% of all testing (*n* = 8,369; 7.9%). The mean scores are more difficult to interpret because of the tri-modal distribution of tests per sample (reference Table 1).[18] Even so, the general pattern is reflected in our measure of central tendency: predominantly African American blocks have mean intensity scores that are uniformly higher than blocks where residents are predominantly white.

While these data lend support for our earlier claims, the analysis of intensity also diverges from the patterns examined thus far in two respects. First, the blocks with the *highest* mean intensity scores overall are those with zero population. Soil and sediment collected from blocks with no residents underwent 138 unique tests, on average. This is sixteen more tests than the highest mean score among populated blocks (122.6) and seventy-eight more tests than the populated blocks with the lowest mean score (60.2). These differences present a stark contrast to corresponding scores for density and duration, where sampling points in unpopulated blocks are least densely clustered (with a sample-to-block ratio of 1:17.2), and where the duration of sampling activity was shortest (101.3 days). Second, those blocks with the *lowest* mean intensity score are not blocks with predominantly white residents as we might expect given earlier findings, but instead are racially integrated blocks. This finding also contrasts to the other dimensions of knowledge investment,

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[18] Just over a quarter of all samples (26.6%) were tested for 193–195 different analytes but another quarter (25.7%) were tested for the presence of just one or two analytes, while the largest proportion of samples (44%) received tests for 124–128 different analytes.

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Table 2 – Knowledge investments by race (percent black).

	DENSITY			DURATION			INTENSITY		
	Num. of blocks (%)	Num. of sample points (%)	Mean[b] (sample-to-block ratio)	St. Dev.	FIRST and LAST days of visit after Katrina	Mean[c]	St. Dev.	Num. of tests (%)	Mean[d]	St. Dev.
Zero pop. blocks[a]	1,955 (27)	119 (12.5)	0.058 (1:17.2)	0.380	13	244	101.3	16,456 (15.5)	138.29	71.5
Pct. Black blocks:										
<20%	1,062 (14.7)	74 (7.8)	0.071 (1:14.1)	0.414	14	175	107.7	6,562 (6.2)	88.7	97.0
20–39%	262 (3.6)	19 (2.0)	0.069 (1:14.5)	0.268	18	176	102.9	1,807 (1.7)	95.1	98.3
40–59%	354 (4.9)	45 (4.7)	0.138 (1:7.2)	0.792	15	222	152.6	2,710 (2.5)	60.2	77.6
60–79%	571 (7.9)	50 (5.3)	0.084 (1:11.9)	0.350	13	246	122.5	6,130 (5.8)	122.6	77.5
80–100%	3,027 (41.9)	644 (67.7)	0.213 (1:4.7)	0.702	14	250	160.4	72,740 (68.4)	112.9	66.2
Total	7,231 (100)	951 (100)						106,405 (100)		

Sources: 2000 U.S. Census, block-level population counts for Orleans Parish, LA; EPA Hurricanes Katrina and Rita Response Project (http://oaspub.epa.gov/storetkp/dw_home). Notes: a. Includes blocks, parks, streets and medians, traffic circles, industrial areas, and minor anomalous polygons with no residential population. b. Mean for density calculated as num. of sample points/num. of blocks. Because differences between means are small, to ease interpretation we also report inverted sample-to-block ratios that describe the number of blocks "represented" by each sample point. c. Mean for duration calculated as days after Katrina/num. of sample points. d. Mean for intensity calculated as num. of tests/num. of sample points.

where integrated blocks receive the second-highest scores for density and duration. These divergent patterns are most likely the result of unpopulated blocks receiving comparatively fewer tests in the 1–2 analyte range and integrated blocks receiving comparatively more such tests. This finding is significant because it illustrates how the environmental interests served by knowledge investment are variously distributed across multiple dimensions—a point we return to in our discussion.

6. Income distribution of knowledge investments

New Orleans is a poor city, with a median household income of $27,133 in 2000. This is sixteen percent below the Louisiana state average and thirty-five percent below the national average. If we only consider the flooded zone of the city, the median household income would be even lower since the wealthier households tended to be in the higher elevation neighborhoods that did not flood. Across those flooded blocks income increases stepwise, with the wealthiest block groups making up the smallest proportion of the floodprint population (10.2%) and the poorest block groups making up the largest (32.6%) (Fig. 7).

Table 3 presents our analysis of density, duration, and intensity in relation to median household income. The general pattern described by the racial distribution of knowledge investments is also reflected in the income data. Across our three measures, knowledge investments are inversely related to income. The EPA collected more samples, over longer periods, and conducted more tests on the sampled material in lower income block groups than in higher income block groups. As in the previous analysis, the pattern is most pronounced as measured by density. The sample-to-block-group ratio in the fifth or lowest income category provides twice the representation as the fourth, four times as much as the third and second, and five times as much as the first or wealthiest income category. Also in line with our earlier findings, the standard deviation in the lowest income category is on average three times larger than those in other categories suggesting again that where the density of knowledge investments is greatest, the benefits of those investments may be distributed most unevenly.

While the dominant pattern in the income data is similar to our findings in the race analysis, the trend is also somewhat weaker. We do not find the same levels of variation across income categories in our measures of duration and intensity, nor do we find increased investments in our middle income category as we did for areas characterized by residential integration. But if the overall trends are weaker, they are also more uniform, and this uniformity further strengthens our basic claim that knowledge investments were concentrated in disadvantaged (black and poor) blocks/neighborhoods. Moreover, the muted impacts we find in this analysis likely are due in part to the way that race and income are correlated in New Orleans. While the vast majority of low-income city residents are African American, there is more racial heterogeneity at middle and upper income levels. At the same time, residential segregation patterns in the city are most intense at lower and

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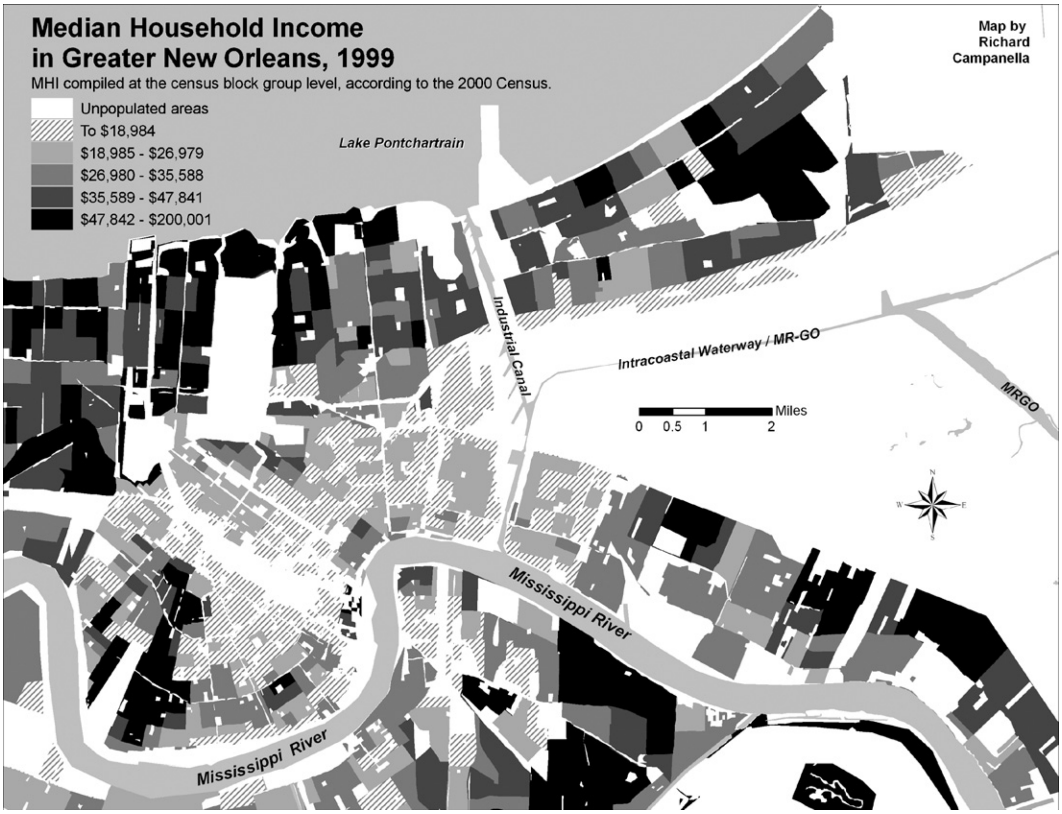

Fig. 7

upper-middle income levels. For example, the middle-class West Lake Forest neighborhood is 95.3% African American, while similarly middle-class Lakeview neighborhood is 94% white. Both neighborhoods were covered with Katrina's flood waters. These and other hypersegregated middle and upper-middle income areas go some way toward muting the distributional inequalities of income in the EPA data.[19]

7. Discussion

Overall, our study shows that knowledge investments accumulate in areas where African American residency is above sixty percent and where annual median household income is below $27,000. While striking, this general finding does not lend itself to straightforward interpretation. Rather our analysis reveals a more complicated story, as expected given the size, suddenness, and unprecedented scale of the disaster and the government's response. Moreover, the analysis raises several normative questions that our preliminary study cannot fully answer and for these reasons we caution readers against drawing unwarranted conclusions from an overly-simple reading of the data. First and foremost, a more careful and accurate interpretation requires attention to two empirical complexities that emerge from the analysis.

The first involves reconciling anomalous intensity scores. In Table 2 we saw that blocks with no residents ranked highest in intensity and lowest in density and duration, and in racially integrated blocks the pattern was basically reversed. In both types of blocks, but much less so in others, mean intensity is strongly and inversely related to density and duration. Why is this? We believe the answer lies in the logic of knowledge production revealed by our analysis. Over time, the relative amount of knowledge produced by testing diminished, as institutional efforts to characterize environmental hazards became increasingly focused on ''hot spots'' for lead, arsenic, or benzo(a)pyrene (in Phase III) and as systematic efforts to identify hazards (in Phase IV) focused on a suite of analytes one-third smaller than in earlier phases. The high mean intensity in zero population areas indicate that there was relatively little follow-up in these areas (thus the low duration score), and consequently less testing with fewer analytes. In racially integrated areas, conversely, relatively more follow-up sampling and more testing for fewer contaminants resulted in a lower mean. In short, under the logic of EPA's hazard assessment, increasing investments in knowledge potential (i.e. more sampling over time) led to relative decreasing returns on investments in knowledge production (i.e. fewer aggregate tests per sample). Where this dynamic is accentuated, lower mean intensity scores may counter-intuitively signal more knowledge investments rather than fewer. To the extent that this nuanced interpretation provides a more

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[19] This weaker pattern may also be a result of aggregation by spatially coarser block-groups instead of blocks, as coarser spatial aggregation tends to smooth out extremes or from the fact that MHI is a measure of central tendency as opposed to a percent of an absolute count.

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Table 3 – Knowledge investments by median household income (MHI).

		DENSITY			DURATION				INTENSITY		
	Num. of block groups	Num. of sample points (%)	Mean[a] (sample-to-block-group ratio)	St. Dev.	FIRST and LAST days of visit after Katrina	Mean[b]	St. Dev.		Num. of tests (%)	Mean[c]	St. Dev.
MHI Block Groups:											
$47,842–200,001	178	91 (9.6)	0.511 (1:2)	2.017	16	205	131.7	72.3	7,037 (6.6)	77.3	89.9
$35,589–47,841	178	111 (11.7)	0.624 (1:1.6)	2.246	14	199	134.0	75.9	12,133 (11.4)	109.3	79.4
$26,980–35,588	178	113 (11.9)	0.635 (1:1.6)	2.338	14	250	139.7	79.6	13,241 (12.4)	117.2	73.7
$18,985–26,979	179	212 (22.3)	1.184 (1:0.8)	3.004	13	250	164.6	75.2	25,065 (23.6)	118.2	65.4
$1–18,984	179	424 (44.6)	2.374 (1:0.4)	7.176	13	247	143.3	75.8	48,929 (46.0)	115.1	69.7
Total	892	951 (100)							106,407 (100)		

Sources: 2000 U.S. Census, block-group level population counts for Orleans Parish, LA; EPA Hurricanes Katrina and Rita Response Project (http://oaspub.epa.gov/storetkp/dw_home). Notes: a. Mean for density calculated as num. of sample points/num. of block groups. b. Mean for duration calculated as days after Katrina/num. of sample points. c. Mean for intensity calculated as num. of tests/num. of sample points.

accurate accounting, it means that racially diverse neighborhoods, although relatively rare in New Orleans, are among those areas that attracted disproportionately high levels of knowledge investment.

A second and related complexity involves the large standard deviations that accompany the dense clustering of sampling points in black hypersegregated and integrated areas (refer to Table 2) as well as in the flood zone's poorest areas (refer to Table 3). Such wide variation around the means indicates highly uneven sampling point distributions within block or block-group categories. This means that a handful of the poorest and most segregated neighborhoods in the flood zone received disproportionately more knowledge investments than wealthier and less segregated blocks *and other demographically similar blocks*. Within poor and (black) hypersegregated blocks, most of the sampling points cluster in just a few neighborhoods. EPA collected many of these samples in a series of adaptive strategies, often in response to public and/or Agency concerns about contaminants from pre-existing hazardous waste sites located in poor and heavily black populated areas. These adaptive knowledge investments targeted known chemical hazards, adding more knowledge to a pre-existing bank of knowledge about the scope and nature of contamination near a select number of hazardous waste sites. As such, these spatially concentrated knowledge investments speak less directly to the general question of urban soil quality following the storm (EPA's institutional mission) than to environmental risks that pre-dated Katrina's landfall. Thus, a more nuanced reading shows that EPA's heaviest investments in place-specific knowledge was in fact very highly concentrated in two distinct types of New Orleans neighborhoods: racially diverse neighborhoods and predominantly black low-income neighborhoods containing known pre-existing environmental hazards.

Following Sarewitz and Pielke (2007), an important set of questions concerns the social value of the distribution of EPA's knowledge investments. In what ways, if at all, did residents in heavy investment neighborhoods ''benefit'' from the additional attention? Do those residents know more about place-based risk in their neighborhoods as a result of EPA's concentrated efforts? Conversely, did the knowledge generated in neighborhoods that received fewer investments provide residents with adequate or inadequate risk information?

We can begin to grapple with such questions by noting that the adequacy of information generated in low-investment neighborhoods rests on the assumption that the absence of the evidence of environmental hazards is evidence of the absence of environmental risk. This assumption may expedite regulatory agency's initial response to urban-scale disaster, but it is questionable over the longer term from the perspective of science and public health. On the other hand, most people living near or on top of known hazardous waste sites before Katrina were already well aware of their precarious situation. That they would still be living in conditions of environmental risk upon returning to their old neighborhoods may not constitute new knowledge so much as reconfirm what former residents of those neighborhoods already knew. In this situation, belated attempts to amend old environmental inequities may create the appearance of

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fairness in government action, but those additional investments in already contaminated areas may come at the cost of drawing down limited resources and inadvertently generating new forms of knowledge inequality.

A related question concerns the reconciliation of the supply of and public demand for knowledge in disaster contexts. Does the unevenness of EPA knowledge investments conform to the actual location-specific needs of city residents (which varied by neighborhood)? While the data we examine in this study cannot answer this question directly, we can address this question indirectly by considering whether repopulation patterns are being influenced by the previous patterns of knowledge investment. Here we see evidence of a negative correlation between the knowledge investment and repopulation patterns. The latest block-level population estimates for New Orleans show that the areas that EPA targeted for concentrated knowledge investments in the year following the flood have been among those slowest to repopulate and, conversely, those neighborhoods that accumulated the least knowledge investments from the hazard assessment are among those that are repopulating most rapidly (Greater New Orleans Community Data Center, 2008). Although we do not know whether people are or are not returning to different parts of the city because they know more or less about the potential risks, it is clear that most residents returning to the flood zone are doing so largely without the guidance of direct place-specific knowledge of the presence or absence of contamination. We believe such outcomes run counter to what we might expect from regulatory science done ''right'' (Sarewitz and Pielke, 2007), if by right we mean science conducted in the broad public interest of environmental quality and safety.

8. Conclusion

Knowledge production is a social process whose impacts on society derive not only from stated cognitive and technical goals, but also from how, when, and where knowledge-making activities are organized and implemented. In regulatory science, the relationship between the social organization of knowledge production and the social imprints those processes leave behind can have significant public and policy consequences. The analytical framework presented in this paper offers one way to study those consequences empirically. Using EPA's hazard assessment of post-Katrina New Orleans as an illustrative case study, we examine the organization of knowledge investments to understand how regulatory science is distributed across an impacted population.

While preliminary, our study's main findings are instructive. Knowledge investments are not distributed evenly, but neither do they concentrate in wealthier neighborhoods with predominantly white residents, as we might expect given existing research on environmental inequities resulting from EPA policy and program implementation. Instead, although with notable exceptions, knowledge investment strategies clearly targeted poorer neighborhoods whose residents are disproportionately African American. Those exceptions include racially diverse neighborhoods and neighborhoods contaminated with hazardous waste prior to Katrina.

Beyond its specific analysis of distributional outcomes, the study also illustrates the multidimensionality and interactive nature of knowledge production activities. In this case, what became known depended on where samples were collected and the number of tests conducted with the sampled materials, but also the duration of sampling efforts in any given neighborhood, which generated decreasing returns over time. The result is a highly uneven distribution of knowledge investments, although questions remain about whether those knowledge inequalities reflect actual variation in societal need and about the relative value of informational outcomes in neighborhoods with heavier or lighter investments.

Future research on knowledge investments will be needed to refine these measures and incorporate higher level statistical and mapping techniques that might shed additional light on the organization of regulatory science. Qualitative research that includes textual analysis of policy and research documents and interviews with key informants can augment further the understanding of decision-making processes inside regulatory agencies that shape research design, data collection, analysis, and dissemination. Knowledge investments accrue at each of these stages, suggesting that our efforts to formalize a social assessment of hazard assessment can be deepened as well as extended into comparative research on regulatory responses to large-scale disasters.

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