ANALYSIS FOR TOXIC MATERIALS IN SEDIMENTS FROM HURRICANE IKE IN GALVESTON, TX

A Component of the LEAST Lead Project

Final Report by the University of Texas Medical Branch's National Institute for Environmental Health Sciences Center in Environmental Toxicology, Sealy Center for Environmental Health and Medicine, and Center to Eliminate Health Disparities

A project in partnership with the Galveston County Health District, Galveston Independent School District, and St. Vincent's House

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EXECUTIVE SUMMARY

Introduction. The LEAST Lead Project is a UTMB initiative, in collaboration with city, county, and community organizations, to reduce exposure to and impact of lead among children on Galveston Island. Recently, the director of St. Vincent's House brought to the attention of the NIEHS Center concerns about the safety of the sediment that washed through homes, businesses, and streets due to Hurricane Ike. This led to an additional task of testing the storm sediment for various toxins. The sediment remains distinctly visible on both public and private property several months after the hurricane.

Sampling. Nine samples were collected from various sites from the east end of Galveston Island to around 81st Street. Locations were chosen on the basis of geographic diversity, proximity to industrial sites, socioeconomically diverse residential areas, and areas vulnerable to toxins washed ashore from Galveston Bay, the Galveston Channel, and the Houston Ship Channel. The sites included the East End Flats, Fish Village, 19th St. and Avenue F, 28th St. and Avenue F, 41st St. and Avenue H, 54th St. and Avenue H, 55th St. and Avenue O, and Terminal Drive and 83rd St.

Collection Protocol. Following EPA standard protocols for collection and preservation of samples as well as chain of custody, trained community partners assisted in the collection of sediment samples. These samples were then sent to a National Environmental Laboratory Accreditation Conference (now called the NELAC Institute) accredited laboratory, Pace Analytical Services, St. Rose, LA, and were analyzed for content of heavy metals (i.e. arsenic, chromium, cadmium, mercury, lead), dioxins, furans, polychlorinated biphenyls, asbestos, sulfur compounds, diesel range organics, and semi-volatile organics.

Findings. The findings of this study are largely good news. No actionable levels of toxins were found in any of the samples collected from the nine sites, indicating that there were no large industrial releases of toxins during the storm. However, levels of arsenic exceeded the EPA screening levels for six of the eight sites tested, and chromium and lead were found in several samples. Dioxin was elevated at one of the two sites tested. There were little or no detectable levels of PCBs, asbestos, sulfur compounds, diesel range organics, or semi-volatile organics.

Concerns. Consistent detection of arsenic above EPA residential screening levels, as well as other metals at lower levels, raises some concerns, given Galveston's pre-Ike burden of metals in the soil. Additional specific concerns include health disparities, exposure to children and vulnerable populations, sensitive land use and activities, and the impact of cumulative risk in a population already physically and mentally taxed by living in a post-disaster community.

Recommendations. Though no action is legally required, according to our findings, we present several recommendations to assist in rebuilding a healthy Galveston with a strong community spirit for protecting our children and ensuring a clean environment. These include the need to:

1. Implement a public awareness and information campaign to support citizens in addressing their own concerns based on risk perceptions;
2. Further investigate issues including illness related to sediment exposure; exposure of vulnerable populations; variations in the toxin levels and additional testing for dioxins and furans across the island; identification of most affected as well as sensitive land use areas; affordable sediment disposal methods; and potential sources of contamination as warranted;
3. Coordinate City services to reduce exposure, such as thorough cleaning of sensitive land use areas and areas combining high levels of pedestrian traffic with higher toxin levels, as well as spraying down of streets and sidewalks before public events; and
4. Develop a comprehensive disaster planning strategy and community education process at local and regional levels for reducing potential future exposure to and release of environmental toxins related to tropical weather events.

1.0 INTRODUCTION

Hurricane Ike made landfall at Galveston, TX in the early hours of September 13, 2008. It was a very large force-two storm that developed an exceptionally high surge tide, reaching 12 feet above mean sea level. The major source of flooding was seawater intruding into the bay side of the island from the Galveston Channel, Galveston Bay and West Bay after the eye of the storm had passed to the north. West and north winds drove most of the surge tide onto the island. The flood waters carried large amounts of sediment, which was deposited widely across the island. Because the sediment may contained material that was stirred up from bottom sediments in the industrialized areas and shipping lanes of Galveston Bay, community members expressed concerns about the possibility that toxic materials might be in the sediments and be a hazard, particularly to children when they returned to areas that had been flooded. In particular, Michael Jackson, Director of St. Vincent's House, a community center and health clinic, asked whether it would be possible to test the sediment for toxic materials. This concern was shared by the investigators conducting a study of lead-poisoning hazards for Galveston Children titled LEAST Lead. The investigators agreed that sediment testing would be a valuable addition to the study, in part because the children who had been the target of the lead-exposure study had largely been displaced from their homes by the hurricane, but might face additional exposures to toxic substances when they returned. The likelihood of exposure to sediment was considered high, especially because many families that suffered damaged housing were cleaning and repairing their properties themselves without adequate protection, often with their children playing or helping in the area. It was, therefore, important to know whether the sediments contained hazardous amounts of toxic materials.

The investigators first inquired about whether other testing was occurring in the community, conferring with the Galveston County Health District (GCHD) and the Texas Commission on Environmental Quality (TCEQ) in particular, and determined that only TCEQ was conducting limited testing. TCEQ's geographic area for testing stretched from South Texas to close to the Louisiana border, with only one sample collected in Galveston, and the range of toxins tested for was limited. After conferring with GCHD and the Galveston City Council, both of whom are key partners through the Childhood Lead Task Force initiative, the investigators met with project funders of the LEAST Lead initiative to request that previously secured funding include sediment testing. The donors unanimously agreed that the project was important and asked that it be done as quickly as possible. Wilma Subra, Ph.D., a respected environmental toxicologist with extensive experience in environmental assessment, was contracted to help design and carry out the sample collection and analysis. St. Vincent's House, a community partner in LEAST Lead, also became a collaborator in carrying out the study.

1.1 Project Objective

The primary goal of the study was to measure levels of hazardous agents in the most heavily flooded areas of Galveston Island that were behind the Seawall, and to determine whether those agents were uniformly distributed or located in specific places. Secondary goals were to outline appropriate steps to reduce exposure to possible toxins, identify issues of health disparities and health vulnerability, and highlight other specific issues needing attention.

1.2 Selection of sampling sites

The initial selection of sampling sites was based on consideration of the possible areas of Galveston Bay from which toxic sediment materials might have been derived. As the image in Figure 1 indicates, sediments could have been carried onto the island from the main channel of Galveston Bay, from the Galveston Ship Channel between Galveston and Pelican Islands, or from West Galveston Bay. At different stages of Hurricane Ike's movement, winds would have driven water onto the bay side of the island from the east, north, or west. Sediments could have been suspended in the flood waters that represented deposits in the main ship channel, the Port of Galveston, or areas of West Bay that may have received runoff or discharges from the Texas City and Chocolate Bayou industrial complexes or the Inter-coastal Waterway.

Criteria for site selection included: (1) a distribution of locations that represented the intrusion of flood water from the areas described above, (2) readily identifiable sediment that could be distinguished from pre-existing soil (see Figure 2), (3) areas that represented different parts of the community, and (4) land uses that were relevant to human use and public health. In order to identify appropriate sites, a preliminary survey of possible sites was made. The sites that were tentatively selected were either on public property or privately owned sites where the owner gave permission for sample collection. A meeting was held on December 6, 2008 at St. Vincent's House to make final selections of which sites would be tested. The meeting included the investigators, Dr. Subra, community members, and a representative from TCEQ.

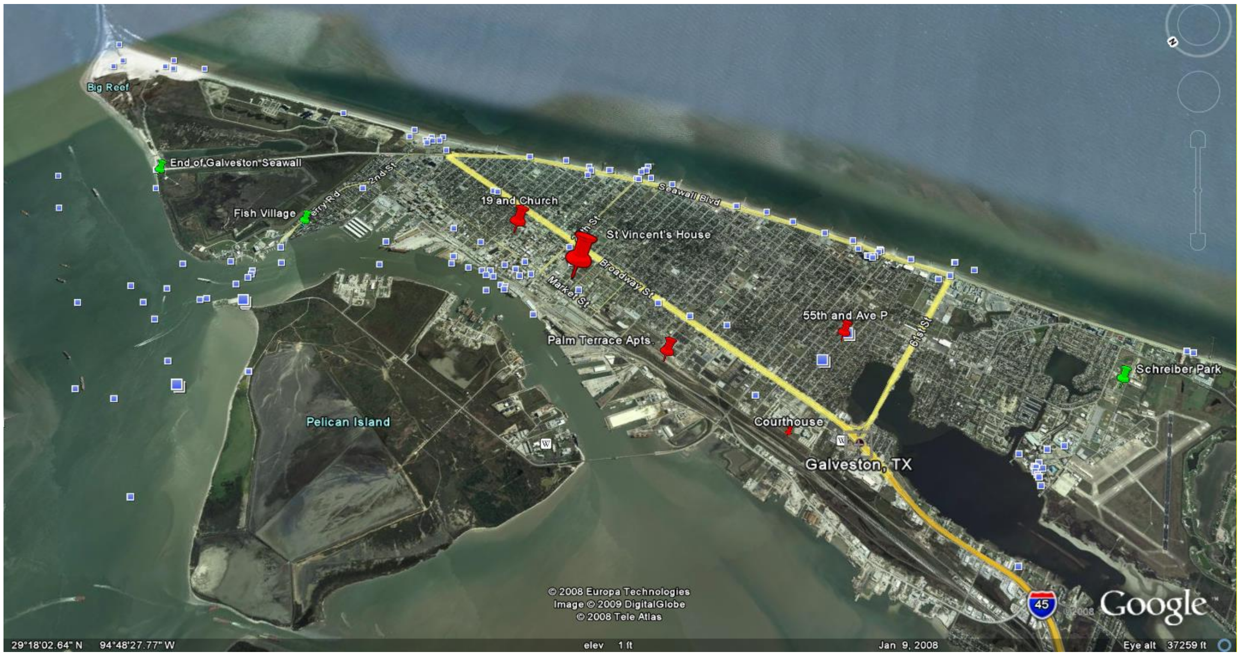

Figure 1. *Locations of sediment collection sites. Red pins indicate levels of arsenic that are of concern. The size of the pins are proportional to the arsenic concentration in the sediment. Green pins indicate arsenic levels that are not of concern.*

2.0 SAMPLING AND ANALYSIS

Evaluation of the sediment was accomplished by collecting samples from multiple locations within the planned time frame and specified areas. This section describes the sampling and analytical methods used to meet the project objective.

2.1 Sample Sites

Each sample site is designated by a number (G-1, G-2…etc.) in the order in which they were sampled. All of the samples were collected between 11:40 AM and 3:20 PM on Sunday, December 7, 2008. The locations of the eight sites where nine samples were collected are indicated by “pushpin” markers in Figure 1. A brief description of each site is provided in the following paragraphs.

- G-1 28th St. and Church: This site was a concrete slab at the intersection of 28th St. and Church (Avenue F). Fresh sediment with a characteristic appearance of fine, silt-like mud that had dried and cracked looking somewhat like cracked and peeling paint.

- G-2 East end of the Galveston Seawall: This site (the East End Flats) was on the beach at the east end of the Galveston Seawall facing the entrance to Galveston Bay, with the Bolivar Peninsula on the opposite side. A depressed area between sand dunes, but above the mean high tide line, was chosen. The area had an active stand of bamboo growing in it. Sediment could be clearly distinguished from sand at this point. When digging into it, the multicolored layers that were evident were sampled. A sample was also collected for analysis for persistent chlorinated hydrocarbons (PCBs) because of the proximity to Galveston Bay and the Houston Ship Channel.

- G-3 Fish Village: This site was in a covered child's sandbox made of plastic in a residential backyard in the Fish Village subdivision, an area northeast of UTMB. The home had experienced flooding to a depth of about 4 feet. The sandbox had originally been filled with builder's sand, which had been purchased new and clean approximately 3 months prior to the storm, and kept covered when not in use. The sandbox had a lid which had been strapped on with elastic cords before the storm. It was still in place when the preliminary site evaluation took place. A distinct layer of darker colored material lay on top of the original sand. This layer was sampled and was also analyzed for sulfate as a control for sample G-5. In addition, a sample was analyzed for persistent chlorinated hydrocarbons because of the proximity to Galveston Bay and the Houston Ship Channel.

- G-4 19th St. and Church: This site was in a utility room at ground level in a building located near 19th St. and Church (Avenue F). A debris line, or water line, was still evident on the outside door indicating that the water had risen to a depth of 73 inches above grade level. A sediment sample was collected off the horizontal top of a steel furnace enclosure that was approximately 30 inches above grade.

- G-5 41st St. and Ball: This site was an abandoned apartment at 41st St. and Ball (Avenue H). The sediment that was sampled covered the tile floor of the unit. The site was relatively close to an industrial sulfur storage facility near the harbor, so a sample was also analyzed for sulfate.

- G-6 54th St. and Ball #1: This site was located on open ground near 54th and Ball (Avenue H) at the former site of cotton warehouses. This area was used for initial storage and processing of debris waste from the hurricane, including grinding of household materials. The area was recently approved for use to construct a community using FEMA trailers to house Galveston residents who had been displaced from their homes. In addition to the usual samples, a sample was collected to analyze for asbestos.

- G-7 54th St. and Ball #2: This site is approximately 220 feet north of the G-6 site on the same grounds. A second sample was collected here for asbestos analysis because the sediment looked more fibrous than was typical of the other samples.

- G-8 55th St. and Avenue O: This site was on a covered patio in the backyard of a residence where the sediment had not been disturbed. The location of the home was near 55th Street and Avenue P. This location is about 3 blocks east of the east end of English Bayou. A debris line on the house indicated that the water depth reached about 6.5 feet above grade. A particularly strong surge came from west to east up Offatts and English Bayou, causing significant structural damage to the homes on the waterfront at the east end of the bayou.

- G-9 Schreiber Park: This site was in the playground on the airport grounds near 81st St. and about 200 yards south of an elementary school. The sample was collected out of a shallow depression under a bench seat where sediment was still evident.

2.2 Selection of Chemicals for Analysis

The criteria for selecting chemicals for analysis were as follows. Chemicals selected for analysis should be those that typically accumulate in marine or freshwater sediments. They should have toxic properties of concern. They should be chemicals that would persist on the ground and pose a potential hazard over a period of time. The cost of analysis would have to be consistent with an overall budget of about $7,500. The chemicals selected fell into the following categories: toxic heavy metals, persistent chlorinated hydrocarbons (polychlorinated biphenyls [PCBs], chlorodibenzodioxins [dioxins], and chlorodibenzofurans [furans]), semivolatile organic chemicals, diesel range organic chemicals, asbestos, and sulfates. The metals included arsenic, cadmium, chromium, lead, and mercury. The persistent organic chemicals were a short panel representing the major congeners of PCBs and several congeners of dioxins and furans. Semivolatile organic chemicals are a large number of polyaromatic hydrocarbons found in soot, tars, and other materials. Diesel range organics are lighter weight organic chemicals that are found in fuels and oils associated with petrochemical refining and marine operations. Not all sites were tested for all toxins. For instance, asbestos was tested only at a site used for initial stockpiling and processing of debris from Hurricane Ike. Sulfate was tested in two locations to determine if elemental sulfur in a storage facility near 48th Street close to the harbor had migrated; one site was relatively close to the storage pile, while the other was far to the east in Fish Village. The selection of chemicals to be analyzed was discussed at the community meeting with the consultant and community members, and also with representatives of the funding organizations. In order to maximize the effectiveness of the study while controlling costs, the number of samples analyzed for some chemicals was limited. Table 1 indicates the chemicals for which an analysis was performed at each site.

2.3 Sample Collection Procedures

All of the samples were collected using procedures that conform to USEPA Guidelines.[1] The sample collection team included community members as well as the investigators. Dr. Subra provided training to the sample collectors. Sediment was collected in areas where it could be distinguished from pre-existing soil or other material. In several locations the sediment was collected off of solid surfaces such as concrete slabs, flooring, or machinery. In three locations the sediment was collected from locations that were covered and not affected by rain or sun exposure following the flood event. The sediment was collected into acid-washed glass sample jars with screw-capped lids that were provided by the analytical laboratory. A clean stainless steel spoon was used to scrape the sediment from the surface as shown in Figure 2. The individual collecting the

Figure 2. *The sample collection procedure included use of protective equipment and documentation through chain of custody forms.*

sample wore nitrile gloves that were changed for each site, an N-95 dust mask, and safety glasses. Separate samples were collected for each class of chemicals to be analyzed. The sampling process was documented on chain of custody forms, in a laboratory notebook, and on sample-jar labels. In addition, the site and sample collection process was documented at each site with still photographs and a video recording. These will be used for the preparation of a video report documenting the entire process.

On December 18, 2008, investigators returned to each of the sites to record map coordinates using a GPS device.

2.4 Sample Analysis

All of the samples were shipped together, in an insulated cooler containing refrigerant blocks, to Pace Analytical Services in St. Rose, LA. They were shipped by overnight express on December 8^{th} and arrived December 9^{th}. The analyses were conducted using laboratory practices specified by the Environmental Protection Agency and several state agencies including the Texas Commission on Environmental Quality (TCEQ). A report was received from Pace Analytical with the results of all tests on January 7, 2009, and is available on request. The results provided in this report are summarized from the quantitative analysis reported by Pace Analytical.

3.0 FINDINGS

Quantitative findings from the sample analyses are shown in Table 1, including each result for each toxin tested at each location. A list of the health effects for each of the major toxins that were detected at significant levels is found in Table 2. Six of the eight samples exceeded the EPA Residential Screening Level (RSL) for arsenic, but none exceeded the Protective Concentration Level (PCL), which would require remediation (further explanation of the meaning of these levels is provided in the Discussion section). Arsenic was both the most widespread and the most elevated toxin found in the study, showing the highest levels in the area just west of the Strand (sampled at 28^{th} St. and Church). Four of eight samples contained levels of chromium that were near, but did not exceed the EPA RSLs. Lead was also found at three sites that might be considered “of concern” given Galveston’s already heavy lead burden in the soil. Dioxin levels at one of the two sites tested were above the detection limit but below the RSL. Since only two sites were sampled, it might be appropriate to sample some additional sites to determine whether there are higher levels at locations where other chemicals of concern were found.

The two samples (G-2 and G-3) that did not contain detectable levels of arsenic were collected from the east end of the Galveston Seawall (on the beach) and in Fish Village, sites which represent the eastern-most samples collected. These two locations also did not contain detectable levels of cadmium and mercury, and they contained the lowest levels of chromium and lead, suggesting a consistently lower level of hazard in the sediment there. However, one of these sites measured detectable dioxin levels.

3.1 Findings at Specific Sites

Samples G1, G4, G-5, and G8 had the highest levels of heavy metals, the chemicals of greatest concern that were detected in this study.

- **28^{th} St. and Church (Ave F)**
  Sample G-1 contained the highest concentrations of arsenic, chromium, and lead, and the second highest concentrations of cadmium and mercury. It represents the most contaminated location for heavy metals. The arsenic concentration of 18.8 mg/kg was 48 times the EPA RSL for arsenic. The chromium concentration of 29.3 mg/kg was just below the EPA RSL of 30 mg/kg for Chromium VI. The lead concentration of 216 mg/kg was more than half of the EPA RSL of 400 mg/kg.

- **55^{th} St. and Avenue O**
  Sample G-8, in the English Bayou area (near the east end of Offatts Bayou), contained measureable levels of all of the heavy metals. The sample at the G-8 location contained the highest concentration of cadmium and mercury, the second highest concentration of lead, and the fourth highest concentration of arsenic and chromium. The arsenic concentration of 8.32 mg/kg exceeded the EPA RSL of 0.39 mg/kg by 22 times. The cadmium concentration of 2.15 mg/kg and mercury concentration of 0.117 mg/kg were the highest values detected in all the samples. The lead value of 210 mg/kg was more than 52 percent of the EPA RSL.

- **41st St. and Ball (Ave H)**

  Sample G-5 contained the second highest concentration of chromium, and the third highest concentration of arsenic. The arsenic level of 8.51 mg/kg was 22 times higher than the EPA RSL. The chromium level of 22.1 mg/kg was 74% of the EPA RSL for Chromium VI. The sample also contained measurable levels of lead and mercury.

- **19th St. and Church (Ave F)**

  Sample G-4 contained the second highest concentration of arsenic, and the third highest concentrations of cadmium, chromium, lead, and mercury. The arsenic concentration of 11.5 mg/kg exceeded the EPA RSL of 0.39 mg/kg by more than 29 times.

- **East End of the Galveston Seawall and Fish Village**

  The dioxin and furan concentrations and equivalence factors in both samples, G-2 from the east end beach and G-3 from the Fish Village area, were below the EPA RSL of 3.9 ng/kg. The sample from the beach (G-2) contained two dioxin congeners and one furan congener,[2] while the sample from Fish Village (G-3) contained four dioxin and three furan congeners. The individual dioxin and furan congeners in the samples for which Target Remedial Goals for Unrestricted Use have been established, were below the goal levels. The concentrations of dioxin and furan congeners are much higher in the Fish Village area and are of concern. The sample from the Fish Village area contains an elevated concentration of OCDD, a dioxin congener, (290 ng/kg); detectable concentrations of 1,2,3,4,6,7,8-HpCDD (21 ng/kg); 1,2,3,7,8,9-HxCDD (0.80 ng/kg); and 1,2,3,7,8-PeCDD (0.54 ng/kg). OCDD is one of the less toxic congeners in the dioxin array. However, it does readily bioaccumulate (build up) in humans and has been associated with health impacts (ref). The sample from the beach at the east end of the Seawall contains OCDD (8.30 ng/kg) and 1,2,3,4,6,7,8-HpCDD (0.77 ng/kg). The beach sample also contained OCDF (0.38 ng/kg). Because they were detected at sites that had low concentrations of other chemicals of concern, it might be advisable to test some of the other sites for these chemicals.

The PCB-equivalence factors in sample G-2 from the beach was well below the EPA RSL for PCBs of 220,000 ng/kg, and contained five PCBs (118, 105, 167, 156, and 157) in concentrations above calibration range. The sample from the Fish Village area (G-3) did not contain any PCBs in concentrations above the calibration ranges.

- **54th St. and Ball (Ave H)**

  The Federal Emergency Management Agency (FEMA) had requested that TCEQ perform a detailed soil analysis in the area where they were considering locating a trailer community at the old cotton warehouse site between Broadway and the Galveston County Justice Center. This was the area where samples G-6 and G-7 were collected. TCEQ rapidly responded to our request to see the results of their analysis. A specific concern was levels of arsenic, since it was the only analysis that exceeded the EPA RSL. Our analysis showed arsenic to be present in the surface sediment at 4.35 mg/kg. The TCEQ sampling was processed differently from ours in that they collected boring samples of soil at depths of either 0 to 2 feet or 2 to 4 feet. Most of their samples contained arsenic at levels between 1 and 3 mg/kg. Only a small fraction of the 0-2 foot borings represented surface material; thus the results for arsenic between their soil samples and our surface sample seem consistent with each other. They are all well below the arsenic PCL for combination exposures to total soil of 24 mg/kg. Our project tested the site for additional toxins, thereby adding to our knowledge on safety at the site. Notably, samples G-6 and G-7 did not contain any detectable levels of asbestos, a potential issue of concern given previous grinding of household debris collected after the storm. Sample G-6 contained 20% fibrous, non-asbestos materials, and sample G-7, where the ground surface had dried and peeled up like old paint, contained 35% fibrous, non-asbestos materials.

Table 1. *Quantitative Findings at all Sample Sites*

Sample	Site Description	Heavy Metals (mg/kg)					Dioxins (ng/kg)**	Semi- Volatile Organics	Sulfate	Diesel Range Organics	Asbestos	PCB (ng/kg)**
		Arsenic	Cadmium	Chromium	Lead	Mercury						
G-1	28th and Church St.	**18.8***	1.05	29.3	216	0.0902						
G-2	East End of Galveston Seawall	ND	ND	1.29	2.61	ND	0.016	ND		ND		0.452
G-3	Fish Village	ND	ND	2.26	2.79	ND	0.91	ND	8,440 mg/kg			0.00186
G-4	19th St. and Church St.	**11.5***	0.697	20.8	76.9	0.0632		ND				
G-5	41st St. and Ball St.	**8.51***	ND	22.1	37.1	0.0468			7,800 mg/kg			
G-6	54th St. and Ball St. #1	**4.35***	ND	4.26	22.6	0.0225					ND	
G-7	54th St. and Ball St. #2										ND	
G-8	55th St. and Avenue P	**8.32***	2.15	19.3	210	0.117		398 ug/kg (Fluoranthene)				
G-9	Terminal Dr and 83rd St. (Schreiber Park)	**1.08***	ND	4.31	10.3	ND						
BLANK							0.023					0.00221
	EPA Residential Screening Levels 1/million	*0.39*	*39*	*30*	*400*	*23*	*3.9*					*220,000*
	Protective Concentration Level Standard 1/10,000	*24*	*6500*	*120*	*500*	*2.1*						

[bold]* *Sample exceeded EPA Residential Screening Levels, for which the EPA suggest "further study is warranted"*

ND: None Detected

Chromium Screening Level is for Chromium VI. The screening level of total chromium is 210 mg/kg

*** Normalized with equivalence factors for congeners*

4.0 DISCUSSION

4.1 Explanation of Screening Levels for Chemicals in Sediments

The USEPA and TCEQ, as well as other environmental regulatory agencies, develop screening levels to use in interpreting the hazards associated with the concentrations of specific agents that are found in environmental samples. For soil or sediment, several different screening levels have been defined, which are benchmarks for different degrees of risk and call for specific actions such as remediation. The screening levels are usually derived from health-based risk assessments. The formulas used to calculate the screening levels may vary depending on the purpose of the screening level and the projected use of the land being considered. For example, screening levels for residential soils are typically based on more protective health risk estimates than would be the case for soil in locations to be used for industrial activities.[3]

Two sets of criteria were used in interpreting the results of the analyses: the Residential Soil Screening Levels and the Protective Concentration Levels. The established thresholds for these standards are listed at the bottom of Table 1.[4]

- **The Residential Soil Screening Levels:** (RSLs).[5] RSLs are derived from risk assessments for the individual chemicals conducted by the Integrated Risk Information System (I.R.I.S.) at the EPA. These screening levels are based on either the cancer risk for those chemicals that have carcinogenic activity or the reference dose (RfD) for non-carcinogens. For chemicals that have carcinogenic activity, the screening levels are set to prevent a risk of more than one excess cancer death in one million lives. This is a very stringent health standard used to set a level that can be assumed to be "virtually safe". It is not unusual for these levels to be below typical background levels for contaminants in soil, so they are not used as a basis for making decisions regarding remediation. The EPA states that "generally, where contaminant concentrations equal or exceed soil screening levels, further study or investigation, but not necessarily clean up, is warranted."[6]

- **Protective Concentration Levels:** Screening levels that are used for actions, such as remediation at hazardous waste sites, are typically made using the same process but by using higher risks as a basis for acceptable levels. These screening levels are often set by state, region, or even for a specific site. The State of Texas has a Texas Risk Reduction Program (TRRP) that is administered by TCEQ.[7] For contaminants in soil, screening levels that are called Protective Concentration Levels (PCLs) are used to define soil concentrations that require remediation.[8] The PCL is intended to protect against adverse health effects after 30 years of exposure via mixed routes: ingestion of soil, inhalation of dust, or skin contact with soil. This criterion was developed as part of the Texas Risk Reduction Program by the TCEQ. Typically it is based on the same risk assessments as the residential screening levels. These levels are used by the Texas Risk Reduction Program (TRRP) as conservative soil cleanup levels for chemicals of concern.[9]

4.2 Interpretation of Results Based on Screening Levels

The results summarized in Table 1 demonstrate that only one chemical for which the sediments were tested exceeded the Soil Screening Level for residential soil: arsenic. As a result, we can conclude that the other heavy metals, petroleum products, and persistent chlorinated organic chemicals are not present at concentrations that would be expected to pose a health risk.

The interpretation of the results for arsenic requires further discussion, as levels were found in the sediment up to 18.8 mg/kg. The residential Soil Screening Level for arsenic is 0.39 mg/kg, based on an estimated cancer risk of one excess cancer death in one million lifetimes of exposure. At the same time, the median level of arsenic in soil in Texas, or “background” level normally found is soil, is 5.9 mg/kg with a range of 1.1 to 18 mg/kg, based on a study by the US Geological Survey. Because of uncertainties in the cancer risk assessment used, the PCL for total exposure by oral, inhalation, and dermal pathways for residential soil ($^{Tot}PCL_{Comb}$) is set at 24 mg/kg.[10]. This level is intended to protect against long-term exposures of 350 days per year for 30 years. Therefore, the arsenic levels measured in the sediment samples collected on Galveston Island fall into what we might consider the normal range of values, based on typical values found in the US Geological Survey as well as the PCL. The TCEQ also tested sediment at three sites on Galveston Island; two were near our sample G-4. Their results are very similar to ours, about 7 and 10 mg/kg compared to 11.5 at G-4. TCEQ also conducted soil testing at the site of the old cotton warehouses near the Galveston County Justice Center and the site of our samples G-6 and G-7. They took many samples at depths of 0-2 feet and 2-4 feet. These samples would have included very little surface sediment. The arsenic levels in most of their samples fell in a range of 1 to 3 mg/kg.[11] If those results reflect typical soil levels in Galveston, then several of our samples contained more arsenic than the soil. The samples with the highest arsenic concentrations were located in areas that that probably received sediment in flood waters from the Galveston Harbor Channel and, to a lesser extent, from Offatts and English Bayous (see Figure 1 and Table 1).

Because the arsenic levels measured in this study are below the ${}^{Tot}PCL_{Comb}$ of 24 mg/kg, there appears to be no requirement to remove the sediment. However, it would seem prudent to avoid contact with them over a prolonged period of time and to prevent children from coming into contact with them. Residents or others who handle sediment should use the same precautions that have been recommended for general cleanup of storm debris. This includes the use of personal protective equipment such as gloves, eye protection, an N-95 dust mask, and clothing that will protect the skin from contact with the material. It would be prudent to remove the sediment from areas that children may frequent, such as patios, yards or playgrounds.

Polychlorodibenzodioxins (dioxins) were assessed at only two sites. The levels at both sites were below the residential screening levels, but at the site in Fish Village, a residential area, it was higher than at the east end of the seawall. It is not clear whether this limited number of samples reflects the concentrations at other locations on the island. Because of the persistence of dioxins and the high toxicity of some congeners, it might be worth considering testing at additional locations where other chemicals were found at higher levels, such as at or near the location of sample G-1.

Figure 3: *The sediment from Hurricane Ike found in Galveston has the smooth texture of fine mud that cracks when it dries. It is generally about 1/8 of an inch thick, and was clearly visible on hard surfaces such as concrete sidewalks. It is notable that at each of the preliminary sites visited, obvious sediment could easily be found despite several hard rains since the storm.*

4.3 Likely Sources of Toxins Found

Arsenic is widely distributed in soils. In many locations it is naturally occurring but may be present as a result of human activities, including wood treatment, agricultural use of arsenic containing chemicals, and metal smelting. Elevated levels of arsenic previously had been measured in sediments in Swan Lake, a bay south of Texas City and north of Pelican Island, as well as in a canal that drained from the site of a tin smelter, Tex Tin, that operated for many years in Texas City. Shipping operations and the migration of sediments from other parts of Galveston Bay may have resulted, over time, in the accumulation of arsenic in the Galveston Harbor Channel and Offats Bayou.

The dioxins found are typically related to wood treatment, either from the manufacturing process itself or from leaching from treated wood (e.g. wharf pilings), and vinyl chloride manufacturing. The sediment sample from the Fish Village area contains an elevated concentration of OCDD (290 ng/kg) associated with pentachlorophenol wood treating during the manufacturing process; detectable concentrations of 1,2,3,4,6,7,8-HpCDD (21 ng/kg) associated with Penta wood treating; 1,2,3,7,8,9-HxCDD (0.80 ng/kg) associated with vinyl chloride manufacturing; and 1,2,3,7,8-PeCDD (0.54 ng/kg) associated with vinyl chloride manufacturing. OCDD is one of the less toxic congeners in the Dioxin array. However, it does readily bioaccumulate (build up) in humans and has been associated with health impacts. The sample from the beach contains OCDD (8.30 ng/kg) associated with Penta Wood Treating and 1,2,3,4,6,7,8-HpCDD (0.77 ng/kg) associated with Penta Wood Treating. The beach sample also contained OCDF, a furan congener (0.38 ng/kg).

A hazardous waste site that has leaked dioxins is located in the mouth of the San Jacinto River at the north end of Galveston Bay. A fish-consumption advisory has been in place for the north half of Galveston Bay for many years, and it was extended to include the south parts of the bay in 2008. The reason for the advisory is that species of popular food fish caught in the bay contain unacceptably high levels of dioxins and PCBs. It is, therefore, not surprising to find some of these materials in sediments.

4.4 Concerns Regarding Exposure

Although our results indicated the presence of toxins in the sediment that were below legally actionable levels for remediation, the consistent detection of arsenic well above the EPA Residential Screening Levels, and in some cases approaching the ${}^{tot}PCL_{comb}$ that mandates remediation, indicates likely exposure of residents, especially due to the persistent presence of the sediment several months after the hurricane and after a number of rains. Elevated levels of other heavy metals, as well as some indication of dioxins and PCBs, also alerts us to potential health risks.

Consequently, some concerns arise regarding health disparities and vulnerable populations, land use, specific activities, and the impact of cumulative risk.

- The heaviest toxin levels were found in a particularly poor neighborhood. Without adequate information and self-protection, this community will likely suffer a heavier exposure burden, and may be most vulnerable to the effects of that burden.
- Children, especially those that engage in hand-to-mouth activities, and persons with compromised immune systems or other vulnerabilities are also at increased risk for short- and long-term health effects.
- Playgrounds and other outdoor recreational areas increase exposure as dust can be kicked up from yard play and sports.
- In the short term, efforts to clean up and rebuild properties will expose those who do not wear protective equipment; in the medium term, gardening may create ingestion exposures and landscaping activities, such as lawn mowing, may aerosolize dust and increase inhalation exposures.
- Sediment toxins along with Galveston’s previous heavy metals burden in the soil and in lead-based house paint, as well as more general chronic low-level exposure to chemicals in the geographical/industrial region, may generate cumulative risks for some populations, especially children, the poor, the elderly, and those with immunocompromised systems. Further, the local population would be expected to be under significant physical and mental stress due to the hurricane and its impact, generally adding to the population’s vulnerability to illness.

Table 2. *Health Effects of Key Toxins Detected in the Sediment*

Arsenic: Long-term exposure can cause symptoms such as skin irritation, diarrhea, stomach and intestine irritation and skin changes. Arsenic is classified as a known human carcinogen by US and international health agencies. Arsenic can also cause lower IQ in children, cancers, early mortality, fetal damage, kidney and bladder damage, blood vessel damage and reduced nerve function. It is important to note that dose, duration, and exposure route are relevant to likely health impact in an individual, as is personal vulnerability (including additional stressors). Exposure routes are inhalation, ingestion (including hand to mouth), and skin absorption to a lesser extent. Arsenic is readily excreted in the urine so most of the arsenic taken up will be excreted within a few days. A small fraction may be stored in the body for several months or longer.[12]
Chromium: Compounds exist in different valence states, which have different toxic properties. Chromium (VI) compounds are the most toxic and are known human carcinogens. Breathing high levels of chromium (VI) can cause irritation to the lining of the nose, nose ulcers, runny nose, and breathing problems, such as asthma, cough, shortness of breath, or wheezing. Sperm damage and damage to the male reproductive system have also been seen in laboratory animals exposed to chromium (VI). Skin contact with certain chromium (VI) compounds can cause skin ulcers. Some people are extremely sensitive to chromium (VI) and may develop allergic reactions consisting of severe redness and swelling of the skin.[13]
Lead: The most sensitive targets for lead toxicity are the developing nervous system, the hematological and cardiovascular systems, and the kidneys. However, because of lead's many modes of action in biological systems, lead could potentially affect any system or organs in the body. The effects are the same whether it is breathed or swallowed.[14]
Dioxins. Dioxins are a family of compounds that differ in the number and arrangement of chlorine atoms on the carbon ring structure. These different forms, called congeners, differ greatly in their toxicity and persistence in the body and in the environment. In order to make statements about the toxicity of mixtures or of individual congeners, the effects are normalized to the toxicity of the most toxic congener, tetrachlorodibenzodioxin (TCDD), by using equivalence factors. Short-term exposure of humans to high levels of dioxins may result in skin lesions and altered liver function. Long-term exposure is linked to impairment of the immune system, the developing nervous system, the endocrine system, and reproductive functions. Chronic exposure of animals to dioxins has resulted in several types of cancer. Due to the omnipresence of dioxins, all people have background exposure and a certain level of dioxins in the body, but due to the high toxic potential of this class of compounds, efforts need to be undertaken to reduce current background exposure. Sensitive subgroups include the developing fetus; the newborn, with rapidly developing organ systems; and individuals exposed through their diets (e.g., high consumers of fish in certain parts of the world) or their occupations (e.g., workers in the pulp and paper industry, in incineration plants and at hazardous waste sites, to name just a few). [15]

PCBs: Like dioxins, PCBs are a family of congeners with different toxic properties. Equivalence factors are also used to normalize the toxic effects of mixtures. The most commonly observed health effects in people exposed to large amounts of PCBs are skin conditions such as acne and rashes, and changes in blood and urine that may indicate liver damage among exposed workers. PCB exposures in the general population are not likely to result in skin and liver effects. Animals that ate food containing large amounts of PCBs for short periods of time had mild liver damage and some died. Animals that ate smaller amounts of PCBs in food over several weeks or months developed various kinds of health effects, including anemia; acne-like skin conditions, and liver, stomach, and thyroid gland injuries. Other effects of PCBs in animals include changes in the immune system, behavioral alterations, and impaired reproduction. PCBs are not known to cause birth defects. The Department of Health and Human Services (DHHS) has concluded that PCBs may reasonably be anticipated to be carcinogens. The EPA and the International Agency for Research on Cancer (IARC) have determined that PCBs are probably carcinogenic to humans.
Cadmium: The health effects seen in children from exposure to toxic levels of cadmium are expected to be similar to the effects seen in adults (kidney, lung, and intestinal damage, depending on the route of exposure).[16]
Mercury: The nervous system is very sensitive to all forms of mercury. Exposure to high levels of metallic, inorganic, or organic mercury can permanently damage the brain, kidneys, and developing fetus. Effects on brain functioning may result in irritability, shyness, tremors, changes in vision or hearing, and memory problems. Short-term exposure to high levels of metallic mercury vapors may cause effects including lung damage, nausea, vomiting, diarrhea, increases in blood pressure or heart rate, skin rashes, and eye irritation. The EPA has determined that mercuric chloride and methylmercury are possible human carcinogens.[17]

5.0 RECOMMENDATIONS

The investigators recommend that Galveston City and County officials consult with local, state, and federal authorities to determine appropriate public actions regarding the levels of toxins found. The findings and discussion presented here further suggest that some specific actions may be warranted, and there may be some situations that generate a special interest in reducing exposure. Therefore, we have outlined several recommendations, some of which would be appropriately undertaken by City and/or County officials, while others might be best supported by other entities.

- **A public awareness and information campaign**. Free-flowing information on safety would support citizens in addressing their own concerns based on risk perceptions, which can vary among individuals. Families with small children, especially those who spend significant amounts of time outdoors, might understandably want and benefit from information on extra steps they can take to reduce exposure. Such a campaign might include:

  a. Reminders to wear protective equipment when removing sediment and when cleaning, and possibly, distribution of equipment to lower income residents;

  b. Information on how to best clean up sediment from private property, and how to appropriately dispose of the waste (e.g. if the City sets up a repository for receiving sediment);

  c. Information on what kinds of flooded household goods are safe to keep and what should be thrown away, as well as how to clean items;

  d. Information on keeping children safe from exposure; and

  e. Information on what to watch for and who to contact regarding illness due to possible exposure.

- **Further study and investigation.** Remediation of the soil is not indicated, according to governmental regulations based on the levels of toxins found in this study. However, EPA guidelines suggest that the measured levels of arsenic do warrant further study and investigation. Such investigation could include:

  a. Monitoring reports of illness potentially related to sediment exposure,

  b. Monitoring exposure of vulnerable populations, e.g. children or outdoor workers,

  c. Additional testing of the island to determine variations in the toxin levels found,

  d. Identification of most affected areas, as well as areas of sensitive land use, and

  e. Research into affordable methods for disposing of any large amounts of sediment collected, if needed.[18]

Additionally, although dioxins and furans were found below EPA screening levels, because testing only occurred at two sites and because there is reason to believe that one of those samples may have been artificially low (it was retrieved from a container that had been covered during the flooding), further sampling and testing for dioxin across the island would provide a better evidence base for decision making and risk analysis. Ideally, the potential sources of the dioxin and furan congeners that were detected in the two samples would be evaluated and measures developed to reduce exposure of the human population and decrease the potential for bioaccumulation.

- **Coordination of City services with the goal of reducing exposure**. A precautionary approach might suggest that as city and county workers go about the process of cleaning and restoring the area, special attention should be given to washing sediment from and thoroughly cleaning sensitive land-use areas such as playgrounds, playground equipment, sports fields, recreational areas, and areas with a combination of high levels of pedestrian traffic and higher toxin levels such as downtown and lower-income neighborhoods on the north side of Broadway. City services could be organized to take into account goals to reduce exposure through aerosolization of dust, for instance by frequently spraying down streets and sidewalks, especially before public events, for a period of time until the sediment has washed away.

- **Development of a comprehensive disaster planning strategy** for reducing future potential exposure to and release of environmental toxins. Just as Galveston has a hurricane preparedness plan related to evacuating citizens, it should have a plan for ensuring that citizens always have a safe environment to return to. This would include a comprehensive community-education process for environmental and other public health risks related to tropical weather events. Specific approaches for implementing strategies at the local, regional, and national levels include:

  a. Locally informed and informing workshops to train local governments, community-based organizations, and concerned citizens about the environmental health implications of severe weather events;

  b. Multi-county / regional public forums representing the severe weather issues and needs of areas as diverse as Nueces, Matagorda, Brazoria, Chambers, and Jefferson counties, as well as Galveston County and Island, and the Houston metro area; and

  c. A national conference on the effects of climate change on severe weather events and how these events affect life on the Gulf Coast.

More information about these strategies is outlined in further detail in the document "Communicating Environmental Health Risk in Galveston Post Hurricane Ike."[19]

6.0 CONCLUSION

The findings of this study reveal largely good news. No actionable levels of toxins were identified in any of the samples collected from the nine sites. It is particularly reassuring that the results indicate there were no large industrial releases of toxins during the storm. Some samples detected low levels of chromium, lead, and dioxin, and there were also little or no detectable levels of PCBs, asbestos, sulfur compounds, diesel range organics, or semi-volatile organics. And while levels of arsenic exceeded the EPA Residential Soil Screening Levels for six of the eight sites tested, the levels did not reach a threshold requiring soil remediation. Further, the range of levels of arsenic found in the sediment were in line with "background levels" found in soil in Texas by the US Geological Survey and cited by TCEQ.

In the interest of protecting the public's health to the highest standard possible, and recognizing that vulnerable populations may wish to take further precautionary measures if given the information and opportunity, we have provided a number of recommendations that could effectively be taken up by public or private groups. In particular, the Galveston Childhood Lead Task Force may be particularly well positioned to take up the broader mandate of addressing a number of environmental issues facing our community in the wake of Hurricane Ike, especially those related to child health.

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7.0 APPENDIX: BACKGROUND ON RISK ASSESSMENT

Human health risk assessments are developed through formal processes that identify one or more studies that are considered suitable as base models and then use extrapolation techniques to calculate a risk value. If a chemical is known to be a carcinogen, the risk assessment based on its carcinogenic activity will typically produce the most stringent risk criterion because thresholds, below which there is no risk, are not believed to exist for carcinogens. Based on the dose-response curves obtained from appropriate human or animal studies, an estimate of the cancer risk at a standard exposure level is calculated. This is called a unit risk (UR). The UR includes adjustments for factors that are different for the general population than for the population from which the data were obtained. The UR may be inverted to calculate the exposure levels at which specific cancer frequencies are estimated. For example, a lifetime risk of developing cancer as a result of a specific exposure is often viewed as a minimal risk level so the exposure level that would produce that risk is often used as a screening level. For chemicals that are not carcinogens, a different approach is used that is based on identifying a dose level at which no adverse effect is expected to occur. This "point of departure" is corrected by modifying factors to determine a Reference Dose (RfD) below which an adverse effect in the general population is not expected.[20]

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[1] USEPA 1996. Soil Screening Guidance: User's Guide. Publication number 93554. 4-23. EPA/S40/R 96/018 Office of Emergency and Remedial Response. US Environmental Protection Agency. Washington, DC.
[2] Congeners are variants or configurations of a common chemical structure; for instance, polychlorinated biphenyls (PCBs) occur in 209 different forms, or congeners.
[3] The EPA methodologies for setting soil screening levels are described in the USEPA Soil Screening Guidance: User's Guide and at http://www.epa.gov/reg3hwmd/risk/human/rbconcentration_table/index.htm.
[4] See http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm.
[5] USEPA 1996. Soil Screening Guidance: User's Guide.
[6] ibid.
[7] See http://www.tceq.state.tx.us/remediation/trrp/trrp.html#topic2.
[8] See http://www.tceq.state.tx.us/remediation/trrp/trrppcls.html.
[9] See http://www.tceq.state.tx.us/remediation/trrp/trrppcls.html.
[10] See http://www.tceq.state.tx.us/assets/public/remediation/trrp/trrptbls1_5_042308.xls; Mike Aplin, TCEQ, personal communication, Jon Rauscher, USEPA, personal communication.
[11] Mike Aplin, TCEQ, personal communication.
[12] From the Agency for Toxic Substances and Disease Registry (ATSDR) Public Health Statement on Arsenic, August, 2007.
[13] From ATSDR Public Health Statement on Chromium, CAS# 7440-47-3, September 2008.
[14] From ATSDR ToxFAQs: CABSTM/Chemical Agent Briefing Sheet: Lead, January 2006.
[15] From the World Health Organization, Fact Sheet 225, November 2007.
[16] From ATSDR Public Health Statement on Cadmium, CAS# 7440-43-9, September 2008.
[17] From ATSDR Public Health Statement on Mercury, CAS# 7439-97-6, April, 1999.
[18] Environmental Protection Agency. (September 2002). *Arsenic Treatment Technologies for Soil, Waste, and Water.* EPA-542-R-02-004.
[19] See document at www.utmb.edu/cehd.
[20] Faustman EM and Omen GS. Risk Assessment In. Casarett and Doull's Toxicology. The Basic Science of Poisons 6th ed. Klaassen, CD ed. McGraw-Hill, New York pp. 83-104, 2001. See also USEPA 2005 Guidelines for Carcinogen Risk Assessment. EPA/630/p.03/001F. Risk Assessment Forum, US Environmental Protection Agency. Washington, DC.