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ESTIMATING CHILDREN'S HEALTH RISKS FROM RECREATIONAL BEACH PLAY FOLLOWING AN OIL SPILL

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Environmental contamination from marine oil spills can have damaging impacts on ecosystems and human health. In 2010, an explosion of the Deepwater Horizon (DWH) oil drilling platform resulted in approximately 1,728 km of shoreline oiling. Existing research characterizes health risk from exposure to oil spill chemicals (OSCs) for adults; however, data on impacts to child health are limited. One objective of the Beach Exposure And Child HEalth Study (BEACHES), funded by the Gulf of Mexico Research Initiative, is to estimate health risks to children between walking and six years of age from exposure to OSCs in a post-oil spill scenario during normal recreational beach activity. The National Research Council (NRC) risk assessment framework was adapted to account for child behavior patterns. Child macro- and micro-activity data were gathered from 391 parent surveys and recorded observations of beach play from 119 children from two beaches each in Miami, Florida and Galveston, Texas. Chemical concentration and distribution data for various OSCs (such as alkanes, polycyclic aromatic hydrocarbons, metals, and dispersants) were aggregated from existing literature and combined with micro-activity data to generate cancer and non-cancer risk ranges for oral (non-dietary), dermal, and inhalation exposures. Each

input variable in the risk assessment framework was evaluated to determine which variable(s) have the most significant impact on overall risk estimates. A Monte Carlo analysis (MCA) was conducted to address uncertainty and variability of both the assumed and observed datasets. Finally, a sensitivity analysis was performed to investigate the different distributional assumptions for each model input. These analyses revealed gaps in current research to provide useful information in guiding local, regional, and national public health agencies regarding monitoring of hazards, beach advisories and closures, and media response in the event of a chemical disaster event.

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BACKGROUND (LITERATURE REVIEW)

Overview

Contamination of shorelines from marine oil spills can have immediate and lasting impacts on the social, economic, political, and health makeup of communities and ecosystems. Over the years, there have been a number of oil spills in the United States and around the world, and various methods have been utilized to evaluate the magnitude and scope of these impacts. A risk assessment framework can provide important information to address and predict risks to a population from an adverse environmental event, where ecological and human health risk assessments have been used routinely for various scenarios. This information, in turn, can inform agencies involved in response and establish policy for risk mitigation.[1]

Deepwater Horizon Oil Spill

In April 2010, the BP-operated *Deepwater Horizon* (DWH) offshore drilling rig experienced an explosion that resulted in the deaths of 11 workers, as well as the release of over 205 million gallons of oil[2] and hundreds of thousand tons of hydrocarbon gases into the Northern Gulf of Mexico (GOM) over the course of 84 days. The DWH rig, part of the Macondo Prospect, was located 66km off the coast of Louisiana and was approximately 1500m in depth.[3] This spill marked the largest in U.S. history, surpassing the previous *Exxon Valdez* spill in the Gulf of Alaska. A joint survey conducted in November 2010 by the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey (USGS) estimated that 5% of discharged oil was burned in-situ and 20% was either skimmed or captured. Additionally, 25% was either evaporated or dissolved, while 24% was either

naturally or chemically dispersed. The remaining 26% of oil from the DWH rig was not recovered or dispersed.[4] Data from 2016 found that 22% of surveyed shoreline in Texas, Louisiana, Mississippi, Alabama and Florida contained surface or subsurface oiling.[5] Between May 2010 and June 2011, Louisiana had 3,420 beach closure events (BCE) due to DWH; Mississippi had 2,148 BCE, Alabama had 1,661 BCE, and Florida had 2,245 BCE; Texas did not report any beach closures due to oil contamination.[6]

One method to address the environmental impact of the DWH oil spill was to inject dispersant chemicals, specifically Corexit 9500, directly into the 1500m deep wellhead in addition to surface treatment with Corexit 9527.[7] By dispersing oil at the sub-surface level, responders aimed to prevent large slicks from forming at the surface near the wellhead. This approach limits safety concerns for cleanup ships in the immediate area of the wellhead and did reduce oil impact along the shoreline.[2] Overall, roughly 2 million gallons of dispersants were used for both surface and wellhead treatments between April and July 2010.[7]

The GOM, compared to other nearshore drilling regions in the U.S., comprises a majority of offshore drilling activity.[8] Although there has been an overall decline in marine oil spills since the passing of the Oil Pollution Act of 1990 (OPA), there have been some smaller marine oil spills in the GOM since DWH. In 2016, Royal Dutch Shell addressed a well leak in the Glider Oil Field, about 165 miles southwest of Louisiana. Approximately 88,200 gallons of light crude oil had leaked from a subsea wellhead flow line in the two-day period between detection and response. With the use of skimmers and booms, response units were able to recover 76,600 gallons of oil-water mixture. The remaining oil was left for bio and photo-degradation.[9]

There have been many post-spill studies following DWH to synthesize new research regarding the effects of oil pollution on various ecosystems as well as psychological and physical health of communities and first responders. Studies have also been conducted to explore social and economic changes for industries and society affected by the oil spill. Many of these studies have been funded by the Gulf of Mexico Research Initiative (GoMRI).

Adult Health Impact from DWH

Much of the existing literature on the impact of oil spill contamination on human health focuses on the health of adults, specifically first responders and groups involved in oil spill cleanup.[10] After the DWH incident, over 8,500 U.S. Coast Guard (USCG) personnel were deployed to coordinate and respond to clean-up efforts. Many of these personnel were exposed to crude oil and its byproducts, along with exposure to chemical dispersants. Studies focusing on the physical health of oil spill responders have found positive associations between exposure to crude oil and adverse respiratory and dermal health symptoms in both short-term and long-term instances.[11,12] Furthermore, results from a 2017 study (McGowan et al.) found positive associations between exposure to the chemical dispersant Corexit and ocular, dermal, and respiratory irritation symptoms.[13] Some of these studies have explored the relationship between specific behaviors and adverse health outcomes. For example, the National Institute of Health's GuLF study conducted a prospective study of 32,608 volunteers and workers involved in post-spill cleanup after DWH to assess potential exposure to oil constituents. Utilizing data regarding spill cleanup-related tasks, such as physically collecting oil from water or land, moving hazardous materials, working directly on the rig, or

providing administrative support, the study found that approximately 45% of participants experienced a maximum daily total hydrocarbon exposure level greater than 1.0ppm.[14]

In addition to physical health impacts, some research has considered the psychological and social consequences resulting from the DWH oil spill. Psychological and behavioral-based studies conducted in the immediate aftermath of the spill investigated levels of distress within coastal communities. A 2011 study (Grattan et al.) found clinically significant levels of anxiety and depression within two coastal communities in Alabama and Florida; participants who suffered income-based loss had meaningfully higher scores relating to depression, tension, anxiety, fatigue, confusion and mood disturbance compared to participants who did not experience income-based loss. The former group also had a lower resiliency score and had a higher likelihood of using behavioral disengagement as a coping mechanism.[15] Long-term studies assessing the mental health of affected communities continues, especially for those who had been impacted by Hurricane Katrina; several of these studies utilize frameworks previously established in the aftermath of the *Exxon Valdez* oil spill.[16]

Some studies exploring the social aspect of post-oil spill changes examined how perceived resiliency determined an individual's physical and mental response to disruption of life and livelihood.[17] Other research has analyzed the impact of community resiliency on an individual's response to disaster-related stressors following DWH. Specifically, these analyses outlined how family, local community, and governmental agencies could help those affected respond and adapt to post-disaster disequilibrium by making key resources accessible and available.[18]

Industrial, Economic, and Ecosystem Impact from DWH

Studies evaluating the economic impact from oil spills on affected industries have been conducted. An economic analysis seven years post-spill concluded that DWH contributed to roughly $1.3 billion loss in visitor spending from recreational activities along the northwestern Florida shorelines of the GOM. The study estimated that total losses for this region were close to $2.04 billion in industry output as well as an estimated employment loss of over 20,000 job-years.[19]

In regards to industry, analysts estimated $1.6 billion total revenue loss, $0.8 billion total profit loss, and $4.9 billion total economic loss among commercial fisheries; for recreational fisheries, analysts estimates 1.9 billion of total revenue loss, $1.1 billion in total profit loss, and $3.5 billion of total economic loss due to closures following DWH oil spill.[20] Lastly, several studies have examined the effects of marine oiling on various Gulf ecosystems, such as seabirds, coral reefs, sea turtles, various fish populations, and marine mammals.[3]

Other Major Oil Spill Events

Torrey Canyon

Marine and nearshore oil spills in the US and throughout the world have both experienced downward trends, largely due to changes in national legislation and international agreements; nevertheless, the risk of a major oil spill event remains an issue for many nations.[21] One of the first large marine oil spills occurred in 1967 when the supertanker *SS Torrey Canyon* shipwrecked near the coast of Cornwall, England, depositing approximately 37 million gallons of crude oil on shorelines in England, Spain, France, and the Channel

Islands. At the time, information on the fate, transport and effects of petroleum-related hydrocarbons in water was scarce. A combination of burning, bombing, physical removal, and dispersants was utilized to remove oil from the sea and shore. This event, combined with similar oil spills in the U.S. and Canada, prompted further research on the impact and recovery from oil spills and dispersants on ecosystems and communities. Finally, the magnitude of the *Torrey Canyon* oil spill prompted the passing of the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) by the United States, in addition to other international maritime laws for oil spill response enacted by the United Nations.[22]

Ixtoc I

One of the earliest marine oil spills to originate in the Gulf of Mexico (GOM) occurred in 1978 as a consequence of a blow-out on the *Ixtoc I* exploratory well in the Bahia de Campeche region of Southwest GOM. Between the initial blowout and the capping of the well 290 days later, approximately 145 million gallons of crude oil had leaked into the offshore and coastal zone of the GOM.[2] The oil composition was lighter than that carried by the *Exxon Valdez*, and due to the depth of the well leakage point, a majority of the released oil formed a three-phase emulsion of small droplets and suspended gas bubbles. A small percentage of the oil was burned at the well site; a majority evaporated into the atmosphere, was mechanically removed at the well site through skimmers and absorbent devices, or sank to the bottom of the GOM. Approximately 10-15% was degraded through biological or photochemical means. Less than 1% was deposited on shorelines in Texas, while the remaining 5% (around 6 million gallons) was deposited on the Mexican shoreline.[23] *Ixtoc I* represents the first major oil spill in a tropical marine environment. This region, in particular,

was a large biodiverse subsystem of a larger marine ecosystem in the GOM. The event triggered public concern regarding the acute and residual effects of oil contamination on shorelines and aquatic communities; furthermore, it demonstrated the need for pre-spill information in order to accurately assess the magnitude of post-spill environmental damage.[24]

Exxon Valdez

In March 1989, the oil tanker *Exxon Valdez* discharged approximately 11 million gallons of oil after running aground on the Bligh Reef off the coast of Prince William Sound, Alaska. Due to the nature of the oil (heavy oil), as well as weather conditions and safety concerns, dispersants were not used to mitigate the fate and transport of the oil. As a result, a significant portion of the discharged oil reached the shoreline, affecting approximately 16% of the shoreline of Prince William Sound and 14% of the shoreline of the Gulf of Alaska. Bioremediation from microbial degradation and enhancement with fertilizer was the primary method for oil removal. By 1992, studies indicated that a majority of the oil had been removed from both shorelines and cleanup activities were suspended. At the time, the *Exxon Valdez* incident represented the largest marine oil spill in U.S. history.[2]

Due to the magnitude of the spill, as well as its impact on the local tourism and fishing industry, existing regulations associated with oil production and transport were reevaluated and new policies were enacted to potentially mitigate the risk for future spills.[25] Furthermore, this incident prompted decades of studies of the long-term effects of oil spills on communities and ecosystems, especially in regards to social and mental health from loss of employment or livelihood. Prior to this spill, very few studies gave attention to human health effects from oil spill events. Many of the human health studies from *Exxon Valdez* oil

spill focused on differences in depressive symptoms and community resilience among various indigenous communities; these studies found higher rates of post-traumatic stress disorder and social disruption in indigenous communities where fishing provided the primary sustenance for families. Furthermore, symptoms related to anxiety and depression were higher in the women of these communities.[26] This later laid the groundwork for future research efforts following large oil spill events, and was the catalyst for the passing of the Oil Pollution Act in 1990.[27]

Erika and Prestige

In 1999, the oil tanker *Erika* shipwrecked off the coast of Brittany, France, discharging over 30,000 gallons of oil into nearby water and along 500km of French coastline. Due to the rocky nature of the coast, much of the subsequent removal and cleanup of shoreline oil was conducted by hand.[28] Cross-sectional studies following the *Erika* spill found that although health risks to the general population were limited, cleanup workers and volunteers, most of who had prolonged skin contact with oil, had higher rates of adverse health conditions, such as dermatitis.[26] A few years later, in 2002, the oil tanker *Prestige* experienced a burst tank and consequently released around 18 million gallons of oil into the waters and along 1,000km of coastline near Spain, Portugal, and France. A majority of cleanup activities were conducted by local fishermen and volunteers, many of whom did not use personal protective attire or equipment.[29] Studies from the *Prestige* spill showed prevalence of lesions, low back pain, and neuro-vegetative disorders among bird cleanup workers, as well as higher rates of nausea, respiratory issues, and itchy eyes among workers who reported not using personal protective equipment (PPE), compared to workers who

reported using PPE.[26] The *Erika* and *Prestige* incidents led to a heightened focus on the impact of OSC exposure on human health.[30]

Oil Spill Impacts on Child Health

Few studies have explored the health risk of oil spill contaminants (OSCs) to children. In 2013, a study was conducted to evaluate the effects of OSCs, specifically volatile organic compounds (VOCs), on the respiratory health of children following the 2007 *Heibei Spirit* oil spill on the western coast of South Korea. An initial survey was conducted for 436 children living near or away from the spill area to determine whether the target populations had ever been diagnosed with asthma or experienced asthma-related symptoms in their lifetimes. A skin prick test was also conducted to rule out other inhalant allergies. An analysis of data from pulmonary function tests of child subjects found that children who lived near the coast exhibited significantly lower forced expiratory volume in one second and increased airway hyper-responsiveness compared to children who lived farther from the area of the oil spill. Furthermore, children near the coast had higher prevalence of asthma and wheezing compared to children in the second group.[31]

There are some existing data on the impact of DWH on the health of children. A prospective cohort study (Peters et al.) was conducted between 2012 and 2016 to investigate midterm and long-term physical, behavioral, and mental health outcomes from DWH in women and children living in the most heavily affected coastal communities in Louisiana. The study involved telephone interviews, home visits, bio-specimen collection, and a child impact sub-study of over 2,000 women and 600 children.[32] The study found associations among economic exposure, psychosocial stress, and adverse physical health symptoms.[33]

A 2017 study (Tipre et al.) utilized mail-in questionnaires to assess environmental exposure patterns to OSCs among pre-K to fourth-grade children 11 months post-DWH. A survey was administered to parents of children at six schools in both inland and coastal regions in Mobile, Alabama 11 months after DWH. Results from 180 completed surveys found that families of children in coastal areas were significantly more likely to continue exposure-related behaviors after an oil spill event compared to children from inland communities; namely, the behaviors of focus were fishing and eating caught fish. These families also were less likely (although not significantly) to reduce other exposure-related behaviors, such as visiting beaches and participating in cleanup activities.[34] Both the Peters and Tipre studies utilized self-reports and interviews to estimate exposure to OSCs.

Oil Spills and Policy

Applicable Policy on Oil Spill Prevention and Response

A combination of state, federal and international policies govern procedures for oil spill prevention. One of the earliest statutes was the NCP, enacted in 1968 in response to the *Torrey Canyon* oil spill in Europe. This law contained fundamental procedures for response to both oil spills and release of other hazardous materials. The NCP was later amended with the passing of the 1972 Clean Water Act (CWA), which has provisions for oil spill reporting, liability, and response. Additionally, this act mandates a federally appropriated fund for cleanup and restoration of natural resources. Other early statutes include the 1973 Trans-Alaska Pipeline Authorization Act, which addresses oil spills and corporate liability for the Trans-Alaska Pipeline System, and the 1974 Deepwater Port Act, which regulates oil spills and liability at deepwater oil ports. Lastly, the 1978 Outer Continental Shelf Lands Act

Amendments created supplementary provisions for oil spills originating from extraction facilities that were operating in federal offshore waters.[35]

After the *Exxon Valdez* oil spill in 1989, concerns were raised regarding whether the prevalent policies were adequate in addressing all types and magnitudes of oil spills. Following public pressure to revise existing laws, Congress enacted the Oil Pollution Act (OPA) in 1990, which consolidated all existing statutes under one federal law. The OPA represented the first comprehensive regulation to address oil spills in both U.S. waterways and coastlines.[35] The OPA, along with existing statutes such as CWA, is comprised of two main components: oil spill prevention and preparedness, and oil spill response and cleanup. Some key revisions instituted by the OPA included designation of a responsible authority in the event of an oil spill; expanding the scope and function of the NCP; requiring response plans from oil vessels and facilities; mandating a double-hull design for oil vessels; and creating an overarching liability system.[36]

Coastal state agencies receive funding for recreational water quality testing, monitoring, and public notification through the federal Beaches Environmental Assessment and Coastal Health Act (BEACH Act), which is then distributed to local and regional agencies. The BEACH Act also requires coastal states to adopt water quality standards for pathogen and pathogen indicators. There are no provisions in place, however, for chemical standards.[37]

The U.S. participates in various international treaties for marine pollution and vessel safety. Many of these treaties are regulated through the International Maritime Organization, a subdivision of the United Nations. Global cooperation for oil spill prevention and response

came largely as a reaction to the *Torrey Canyon* oil spill in the English Channel.[22] The most relevant accord is MARPOL 73/78, which includes Annex I – Prevention of Pollution by Oil. This sets guidance for oil spill response, as well as emergency procedures onboard vessels when an oil discharge has occurred. The U.S. follows MARPOL 73/78 protocols through the Act to Prevent Pollution from Ships (APPS). APPS applies both to international vessels in U.S. waters or ports as well as U.S. ships operating in international waters.[36]

Designated Authorities for Oil Spill Response

Jurisdiction of U.S. coastal waters is shared between the coastal states and the federal government. Coastal states, under the 1953 Submerged Lands Act, enforce jurisdiction over resources and submerged lands in waters up to 3 nautical miles from shore. Nonetheless, navigation, commerce, defense, and international activities are still regulated by federal agencies in waters designated under state jurisdiction. The federal government has sole jurisdiction between 3 and 200 nautical miles off-shore, where the exclusive economic zone ends. In the event of an inland oil spill, the EPA has authority; in coastal waters, the USCG is the primary responding agency. This branch has the decisive power to coordinate oil spill response at the national, state, and private-sector level. They are aided by other federal agencies, including NOAA, which collects data to determine impact of OSCs on local ecosystems and communities.[35]

Regulations and Protocols for Beach Closures

The EPA has established protocols to monitor beach quality and deliver information to the public regarding beach advisories or closures. The Beach Advisory and Closing Online Notification system (BEACON) serves as a long-term database of beach advisories and

closures and is available to the public. In addition to water quality standards for pathogens mandated by the BEACH Act, the EPA also periodically publishes water quality criteria for a set of chemical pollutants, known as the Ambient Water Quality Criteria for the Protection of Human Health; the latest list published in 2015 includes 94 chemicals that have the potential to pose a risk to human health. A number of chemicals from this list, such as benzene and fluoranthene, can be found in crude oil.[38] The methodology used to generate this list utilizes variables such as body weight (average for adult human), drinking water consumption rate (per capita estimate for adult humans), fish consumption rate (90th percentile rate for adult humans), toxicity values, and relative source contribution.[39] Although this document serves as an essential recommendation tool for agencies to evaluate their local water quality standards, it does not take into consideration exposure inputs for children.

Risk Assessment: Current Models and Uses in Public Health

Risk is a measure of probability that an event will occur as a result of a given exposure. In broad terms, risk assessment is defined as "a systematic process of evaluating the potential risks that may be involved in a projected activity or undertaking."[40] In regards to environmental health, the EPA defines risk assessment as a "qualitative and quantitative evaluation of the risk posed to human health and/or the environment by the actual or potential presence and/or use of specific pollutants."[41] There are two major types of risk assessment: ecological, which focuses on the risk to the environment and ecosystems, and human health risk assessment, which focuses on the risk to individuals and populations. The risk assessment paradigm has four major components: hazard identification, dose-response assessment, exposure assessment, and risk characterization (Figure 1).[42] Hazard identification

involves identifying any substance that may cause harm, and determining any health effects associated with the substance. Information used in the dose-response assessment includes evaluating data from animal models and extrapolating for various dose thresholds to determine toxicity levels. Exposure assessment characterizes the possible modes/dynamics of contact between the target population and the hazardous substance and any contaminant loading. In the case of human health risk assessment, exposure can be from a single route or a combination of oral, dermal and inhalation exposure routes. The risk assessment paradigm is an iterative process, where data from one step can provide information to other components. These data provide a risk characterization profile for a single hazard or group of hazards. Risk characterization entails using the data from the first three components to determine risk estimates and the overall degree of confidence for those estimates. The risk assessment process can potentially inform health, social, legal and economic decisions for risk management practices.[42]

Risk Assessment Application in Environmental Scenarios

Risk assessment can be applied to a wide array of industries, such as engineering, finance, business and security. Within the bounds of environmental health and safety, risk assessment can be applied to food, water, air, and other environmental and occupational exposure scenarios.[43] Some examples of risk assessment applications include: determining human health risk from waterborne viruses[44] and other pathogens[45]; using QMRA to estimate the impact of contaminated irrigation water on fresh produce[46] leading to microbial standards for food safety[47]; and using risk assessment to ascertain the potential reduction in human health risk from the implementation of an antimicrobial agent in hospital surface treatment.[48]

Risk assessment methods have also been previously used for natural disaster preparedness and damage mitigation. Studies have addressed the integration of risk assessment in response to tornadoes, earthquakes, hurricanes, monsoons and floods.[49] [50] [51] [52]

Ecological Risk Assessment from DWH

Ecological risk assessment constitutes the same general framework as human health risk assessment but also takes into consideration the complexity and sensitivity of ecosystems, as well as indistinct routes of exposure and effects of nonchemical hazards, feedback loops, and other adaptive processes. In many ecological risk assessment scenarios, hazards are often referred to as stressors.[53] Due to the organismal diversity of the GOM, much of the existing risk-related research following DWH focuses on ecological risk assessment. For example, frameworks have been put forth to investigate the effect of DWH on migratory bird populations, estuarine fish, and oyster reefs.[54] [55] [56] These ecological risk assessment frameworks, compared to human health risk assessment, emphasize restoration and recovery practices rather than larger-scale policy recommendations.

Probabilistic Risk Assessment

The EPA established probabilistic risk assessment (PRA), a type of risk assessment process, as a means to carry out mandates from the 1980 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as the Superfund. The Superfund is authorized to assess current and potential threats to human health and the environment from the release of hazardous contaminants, pollutants, and other substances. Specifically, risk assessment is vital to the Remedial Investigation and Feasibility Study (RI/IS), which is an important component to the NCP and informs risk management

decisions within the Superfund. PRA uses probability models to characterize the likelihood of risk levels in a given population; it can also be used to assess uncertainty in risk estimation and identify certain populations that may be at increased risk of adverse health outcomes.[57]

Prior to adoption of PRA, EPA guidelines recommended point estimate methods for risk assessment. This method generates either an average expected risk or maximum exposure estimate of risk, depending on what is used as the input variable. PRA, alternatively, employs probability distributions for one or many inputs of a risk equation, thereby accounting for uncertainty and variability. The generated output of a PRA is consequently a distribution of risk, which can theoretically provide more information on whether risk levels may be exceeded, which in turn can better inform decision-makers.[57]

Monte Carlo analysis (MCA) is one of the most popular methods of PRA. This approach uses computer simulation to merge several probability distributions in a risk equation. Using a specified range, the MCA simulation randomly selects a value for each variable (assuming variables are independent of each other) and generates the resultant risk value. The simulation then repeats this method for many thousands of iterations, each time saving the risk value in order to generate a risk range. Some complex versions of MCA can also take into account variables that are dependent on one another.[57]

Variability and Sensitivity

Generally, risk values produced via point estimates are subject to variability and uncertainty, due to heterogeneity within the target population. Confidence intervals can be used to measure this variability. In a Monte Carlo approach, random values are repeatedly selected, resulting in a probability distribution rather than a discrete risk value. This approach

takes into consideration inter-individual variability and population diversity.[57] Sensitivity analysis is used to establish which input variables or exposure pathway have the greatest influence on a risk estimate. This analysis is especially useful in multimedia fate and transport models, where conducting simulations for every variable and/or pathway is not feasible; additionally, identification of key variables and pathways allows for targeted research efforts.[57]

Integration of Behavioral Data in Risk Assessment

There are examples of studies integrating human behavior data in risk management. Some of these studies address exposure from microbial hazards. For example, a quantitative microbial risk assessment (QMRA) was applied to a 2012 study (Shibata and Solo-Gabriele) to evaluate the health risk to children from exposure to marine beach sand. This study utilized existing behavioral data on child ingestion patterns.[58] In a meta-review of 12 prospective cohort studies comparing adult and child exposure to beach water and sand, children between ages 4 and 12 years were found to have the highest exposure to sand, water and algae compared to other age groups. Moreover, children were four times as likely to ingest beach water compared to adults, and males had a tendency to ingest more beach water compared to females.[59]

Following the *Erika* tanker spill, a human health PRA was conducted to estimate health risks from exposure to previously polluted beach zones in order to aid decisions regarding re-opening these beaches. Results indicated low risk for skin cancer among adult beachgoers, but slightly higher risk for adult beach workers and pregnant women. For

children, this PRA took into account ingestion of tar balls and bathing in seawater, but did not account for other beach play activities.[60]

Black et al. (2016) performed a baseline human health risk assessment on children from exposure to OSCs during recreational beach play in the intertidal zone using existing analyzed samples and datasets from EPA for seven OSCs of concern. This study also derived behavioral and chemical inputs from assumptions of exposure, baseline activity, and exposure variables found in the EPA Exposure Factors Handbook and from the Center for Environmental and Human Toxicology (CEHT) technical reports. The study did not find significant acute or chronic health risk to children from oral, dermal or inhalation exposure.[61] However, child beach activities were estimated from residential soil exposure scenarios; child behaviors specific to beach play were not taken into account. Additionally, exposure duration (e.g., time spent at beaches daily and yearly) was estimated since family beach macro-activity was not available.

One existing example of PRA from DWH involved assessing health risks from consuming contaminated shrimp among a community of Vietnamese adults in Southern Louisiana. This 2015 study by Wilson et al. used combined data from surveys on ingestion patterns with collected samples of locally harvested shrimp to conduct an MCA, which generated hazard quotient distributions for cancer and non-cancer health risk. The population for this study only included adult men and women. The study found that even among frequent consumers of shrimp, consumption of shrimp containing the levels of PAHs detected from collected samples yielded no significant cancer and non-cancer health risk.[62]

Child Behavior Patterns in the Context of Risk Assessment

In human health risk assessment, the combination of behavioral parameters and presence of hazards determines risk of adverse health outcomes.[57] Children might be more susceptible to adverse health outcomes when exposed to the same hazards as adults. Small children, especially toddlers, demonstrate greater risk from non-dietary ingestion due to frequent hand-to-mouth contact, along with oral contact with objects, such as sand. Compared to adults, children practice fewer self-hygiene behaviors, which may put them at risk from prolonged dermal contact with contaminated surfaces. Lastly, children have a tendency to be more physically active than adults, particularly in recreational scenarios such as the beach environment; as a result, they may experience higher exposure via the inhalation route.[63]

PUBLIC HEALTH SIGNIFICANCE

Current literature references many studies on the potential influence of oil spill events on the social and economic infrastructure of an impacted community. There are also a number of studies on ecosystems from contamination from OSCs. Although there are some data on the effects to human health, much of it focuses on the health of first responders and other adult populations. Even in these cases, data are limited. There is little to no evidence investigating the risk of adverse health effects to vulnerable populations, such as children, after exposure to OSCs in the recreational environment. Human health risk assessment can give important insight into the magnitude of risk and what factors are of the greatest importance when determining risk. This analysis can provide valuable information for policymakers when developing regulations and procedures for oil spill prevention. Furthermore, the information generated from this type of risk assessment can offer recommendations to public health agencies involved in setting procedures for oil spill response.[57]

OBJECTIVES

The objectives below are a subset of a larger study titled Beach Exposure And Child HEalth Study (BEACHES). The BEACHES project is a partnership among the University of Miami, the University of Texas Health Science Center at Houston School of Public Health, and North Carolina A&T State University, with funding from GoMRI. The overall goal of the BEACHES study is to determine the health risk to children from OSCs through the integration of play activities with chemical concentration distributions in the beach environment. The study protocol was approved by GoMRI and IRBs at each partner institution.

Objective 1

Using existing and generated nearshore concentrations of OSCs, along with macro- and micro-activity data characterized for children, health risks were estimated for young children (between walking and six years of age) playing in the beach environment. Macro-activity information from family surveys provided information on frequency of exposure to the beach environment (days spent at the beach per year), and micro-activity days from child participation in the BEACHES study provided information on body weight and skin surface area.

Objective 2

Sensitivity analyses using Monte Carlo methods were conducted to determine which model parameters drive health risks.

Objective 3

Policy recommendations were developed to address monitoring of chemical hazards in the recreational water environment in order to inform health communication, beach closures, remediation efforts, and outreach to families impacted by oil spill events. These recommendations were adjusted to align with existing jurisdictional authority limitations at the local, regional, and national level.

METHODS

A full study protocol was reviewed and approved by the University of Texas Health Science Center at Houston Committee for the Protection of Human Subjects (CPHS) Institutional Review Board (Approval # HSC-SPH-18-0396) (see Appendix B).

BEACHES Field Study

Study Design

To address Objective 1, this study utilized data from the BEACHES study, which has collected data on child macro-activity patterns through the use of a written, IRB-approved survey completed by parents of children under the age of seven years. Written and oral consent were obtained prior to administration of the survey.

Child micro-activity data were obtained from the translation of recorded video observations of children from the BEACHES study. Translation was executed by study partners at North Carolina A&T State University and provided for this analysis.

Study Setting

Data collection took place at four beaches; two in Miami, Florida (Figure 2) and two in Galveston, Texas (Figure 3). These beach locations were chosen to evaluate whether geographical differences or beach characteristics, impacted beach-play behavior, perception of risk (by parents), and hygiene behaviors among families.

Data were collected at Crandon Beach, FL from June 21 through 25, 2018 and at Haulover Beach, FL from June 28 through July 1, 2018.

Data were collected at Stewart Beach, TX from July 13 through 16, 2018 and at Seawall Beach, TX from July 18 through July 21, 2018.

Study Subjects

The sample size goal for the video-translation portion of the study was over 100 children between walking age and six years-old. Flyers were posted at local physicians' offices, daycares, and on Facebook groups to recruit parents. Parents were instructed to call or email if interested in including their child/children in the study. Preliminary consent was obtained via a phone interview using IRB-approved protocols. Written consent was obtained onsite at the beach prior to child beach play using IRB-approved documentation. For macro-activity information, a goal was set to collect 400 completed surveys from parents with children under the age of 7 years (200 from each region). These were collected from parents of study participants and from parents with qualifying children who visited the target beaches during the study period. Oral and written consent were obtained from all survey participants using IRB-approved protocols and documentation. Surveys were available in English and Spanish.

Data Collection

Participants were assigned an ID corresponding to a list of numbers from 1-125 and a randomized letter ID of D, W, or S, designating the treatment for hand press procedure (dry, wet, or sunscreen) used for the soil adherence portion of study. Height, weight, race/ethnicity, age, and sex was recorded for each participant on a written ID sheet and later transcribed onto an electronic spreadsheet. Demographic information was paired to the ID. Personal information was de-identified on the spreadsheet for field and survey data. Information on clothing, accessories (sunglasses, water shoes, etc.) and any existing skin abrasions was recorded for each participant. Participants were checked again for skin

abrasions after video recording was complete. Environmental data (water temperature, salinity, and microbial concentration, sand temperature, and ambient temperature and humidity) were collected for each day of videotaping.

Family Survey of Macro-Activity and Hygiene Behaviors

Parents were instructed to complete a written survey to record macro-activities, post-beach play hygiene behaviors, and preferences for communication of beach closures and advisories. Survey responses were later transcribed onto an electronic spreadsheet. Parents could complete surveys prior to arriving at the beach if previously consented (see Appendix C).

Hand and Body Adherence Tests

Participants were assigned an ID corresponding to randomized letter ID of D (dry), W (wet), or S (sunscreen), designating the treatment for hand press procedure. A pencil tracing was made of participants' hands and then cleaned with a clean wet wipe and dry paper towel. The hands were given the assigned treatment (or no treatment if assigned ID contained a D). Next, the participant pressed their hands, palms down, on a tray of sand collected from the beach that same day for a period of ten seconds. The tray was placed on a scale and the resulting weight measurement was taken for hand adherence measures. At the end of the one-hour period, participants were instructed to stand in a collecting pool; clean sea water was passed over the body and appendages of each participant to collect sand and debris for body adherence measures.

Videotaping of Children's Micro-Activity Behaviors

Participant beach play activity was video-recorded for a period of one hour to record micro-activities (contact patterns with object and surfaces, activity levels, and micro-environments visited). Additional observations were documented on paper to make supplement the video-recording.

Human Health Risk Assessment

Risk Models for Oral, Dermal, and Inhalation Exposure

A point-estimate risk value can be calculated using the equations below (Eq. 1 – 5). These are standard equations provided by the EPA to calculate both cancer and non-cancer risk values[57]. In a PRA, point-estimates are generated using randomized values within a variable set; this generates a distribution for a given range of variables (such as concentration, body weight, etc.).

The general equation for risk that will be used in this analysis is:

$$\boldsymbol{Risk = Dose \times Slope\ factor} \tag{1}$$

Calculation for dose is dependent on route of exposure. For oral (ingestion) exposure:

$$\boldsymbol{Dose_{(oral)} = \frac{C \times IR_s \times RBA \times EF \times CF}{BW}} \tag{2}$$

where C=concentration (mg/kg), IR_s=soil intake rate (mg/kg), RBA=relative bioavailability factor (unitless), EF=exposure factor (unitless), CF=oral conversion factor (mg/kg), and BW=body weight (kg). Exposure factor is defined as:

$$\boldsymbol{Exposure\ factor\ (EF) = \frac{F \times ED}{AT}} \tag{3}$$

where F=frequency of exposure (days/year), ED=exposure duration (years), and AT=averaging time (days). For dermal exposure, dose is calculated as:

$$\boldsymbol{Dose_{(dermal)} = \frac{C \times SA \times AF \times ABS \times EF \times CD}{BW}} \tag{4}$$

where C=concentration (mg/kg), SA=skin surface area (cm^2/event), AF=adherence factor (mg/cm^2), ABS=absorption factor (unitless), EF=exposure factor (unitless), CD=dermal conversion factor (mg/kg), and BW=body weight (kg). Lastly, for inhalation exposure, dose is defined as:

$$\boldsymbol{Dose_{(inhalation)} = \frac{C \times \frac{1}{PEF} \times IR_a \times ET \times EF}{BW}} \tag{5}$$

where C=concentration (mg/kg), PEF= soil-to-air particulate emission factor (m^3/kg), IR_a= inhalation rate (m^3/day), ET=exposure time (hours/day), EF=exposure factor (unitless), and BW=body weight (kg).

Averaging time (AT) will differ between cancer and non-cancer risk calculations and can vary in non-cancer risk calculations, depending on the outcome in question.

Variables

A human health risk assessment was conducted by Black et al. (2016) using chemical concentration data from EPA datasets. EPA sample collection began April 28, 2010 and ended October 6, 2010.[61] These chemical concentration values and select exposure variables from the EPA Exposure Factors Handbook were utilized in the BEACHES human health risk assessment.[64] The chemical-specific variables used in the BEACHES human health risk assessment are summarized in Table 1 and the exposure-specific variables used in both the risk assessment by Black et al. (2016) and the BEACHES risk assessment are summarized in Table 2.

A human health risk assessment was conducted in this study using exposure variables from Table 2 and chemical concentration inputs from fate and transport modeling data of OSCs in the nearshore environment. The chemical-specific variables used in the risk assessment for the six initial chemicals are summarized in Table 5. Six chemicals were chosen for this risk analysis. Information for slope factor, relative bioavailability factor (RBA) and dermal absorption factor (ABS) for each chemical was taken from the Center for Environmental and Human Toxicology Technical Report (2005).[65] Values for the following variables - exposure duration (ED), averaging time (AT), exposure factor (EF), soil intake rate (IRs), oral and dermal conversion factors (CF, CD), adherence factor (AD), soil-to-air particulate emission factor (PEF), inhalation rate (IRa), and exposure time (ET) - were consistent with the risk assessment conducted by Black et al.[61]

Datasets were received from colleagues at North Carolina A&T State University with de-identified information on body weight (BW) and total skin surface area (SA) for 119 children who successfully completed participation in the BEACHES study. A dataset of de-identified information for frequency of exposure (F) – number of days per year that population visited the beach, taken from 391 surveys completed by parents of children participating in the BEACHES study and parents solicited for surveys during the field study, was also received. Using these datasets, averages were calculated from each dataset and used in the risk models for health risks from oral, dermal, and inhalation exposure routes. All exposure variables used in this risk assessment, including the three average values for BW, SA, and F calculated from BEACHES data, are summarized in Table 2. Expanded information on body weight, skin surface area, and frequency of visits to the beach from these datasets are summarized in Tables 3 and 4, respectively. The datasets were maintained for subsequent sensitivity and Monte Carlo analysis. Videotaping data was not used in this analysis but will be utilized for future risk assessment applications.

Sensitivity Analysis

Datasets for BW, SA, and F using BEACHES data were used in the sensitivity analysis. A fourth dataset was created for each of the six chemicals chosen for this assessment comprised concentration values from chemical fate and transport modeling data generated from another subproject within the BEACHES study (Montas et al. 2019, unpublished) and existing EPA data from sampling of GOM coastlines following the DWH oil spill. EPA sample collection began April 28, 2010 and ended October 6, 2010.

Concentration values for sediment, weathered oil, and tar were used in this analysis. The remaining variable values can be found in Table 2.

Tables 8 - 13 summarize sensitivity analysis for six chemicals. A point estimate (Trial 1) and five separate simulations (Trials 2-6) were run in Crystal Ball for each chemical.

Trial 1

An average value was calculated for each of the four datasets. These averages were used to generate a fixed point estimate risk value to be used as a comparison for sensitivity. Mean risk values for cancer are summarized in Trial 1 of Tables 8a, 9a, 10a, 11a, 12a and 13a. Mean risk values for non-cancer are summarized in Trial 1 of Tables 8b, 9b, 10b, 11b, 12b and 13b.

Trial 2

In the second trial, average values were used for all variables except for body weight. For body weight, the dataset from the BEACHES study was used. A triangular distribution was chosen in Crystal Ball. The minimum, maximum and median values were used to generate the distribution for this dataset. The simulation was run for 1,000 iterations and probability graphs were generated for total cancer and non-cancer risk, added together using individual risk values from oral, dermal, and inhalation exposure. Mean, 2.5%, and 97.5% percentile risk values for cancer are summarized in Trial 2 of Tables 8a, 9a, 10a, 11a, 12a and 13a. Mean, 2.5%, and 97.5% percentile risk values for non-cancer are summarized in Trial 2 of Tables 8b, 9b, 10b, 11b, 12b and 13b.

Trial 3

In the third trial, average values were used for all variables except for skin surface area. For skin surface area, the dataset from the BEACHES study was used. A triangular distribution was chosen in Crystal Ball. The minimum, maximum, and median values were used to generate the distribution for this dataset. The simulation was run for 1,000 iterations and probability graphs were generated for total cancer and non-cancer risk, added together using individual risk values from oral, dermal, and inhalation exposure. Mean, 2.5%, and 97.5% percentile risk values for cancer are summarized in Trial 3 of Tables 8a, 9a, 10a, 11a, 12a and 13a. Mean, 2.5%, and 97.5% percentile risk values for non-cancer are summarized in Trial 3 of Tables 8b, 9b, 10b, 11b, 12b and 13b.

Trial 4

In the fourth trial, average values were used for all variables except for frequency of exposure. For frequency of exposure, the dataset from the BEACHES study was used. A triangular distribution was chosen in Crystal Ball. The minimum, maximum, and median values were used to generate the distribution for this dataset. The simulation was run for 1,000 iterations and probability graphs were generated for total cancer and non-cancer risk, added together using individual risk values from oral, dermal, and inhalation exposure. Mean, 2.5% and 97.5% percentile risk values for cancer are summarized in Trial 4 of Tables 8a, 9a, 10a, 11a, 12a and 13a. Mean, 2.5% and 97.5% percentile risk values for non-cancer are summarized in Trial 4 of Tables 8b, 9b, 10b, 11b, 12b and 13b.

Trial 5

In the fifth trial, average values were used for all variables except for chemical concentration. For chemical concentration, the combined dataset from EPA sampling and Montas et al. was used. A triangular distribution was chosen in Crystal Ball. The minimum, maximum and median values were used to generate the distribution for this dataset. The simulation was run for 1,000 iterations and probability graphs were generated for total cancer and non-cancer risk, added together using individual risk values from oral, dermal, and inhalation exposure. Mean, 2.5% and 97.5% percentile risk values for cancer are summarized in Trial 5 of Tables 8a, 9a, 10a, 11a, 12a and 13a. Mean, 2.5% and 97.5% percentile risk values for non-cancer are summarized in Trial 5 of Tables 8b, 9b, 10b, 11b, 12b and 13b.

Trial 6

In the sixth trial, distributions were used for body weight, skin surface area, frequency of exposure, and chemical concentration. Fixed values were used for all other variables (Table 2). A triangular distribution was chosen in Crystal Ball for each dataset. The minimum, maximum and median values were used to generate the distribution for these datasets. The simulation was run for 1,000 iterations and probability graphs were generated for total cancer and non-cancer risk, added together using individual risk values from oral, dermal and inhalation exposure. Mean, 2.5% and 97.5% percentile risk values for cancer are summarized in Trial 6 of Tables 8a, 9a, 10a, 11a, 12a and 13a. Mean, 2.5% and 97.5% percentile risk values for non-cancer are summarized in Trial 6 of Tables 8b, 9b, 10b, 11b, 12b and 13b.

Monte Carlo Analysis

Risk equations (1-5) served as the framework to generate probability distributions for a Monte Carlo analysis. This simulation and corresponding sensitivity analysis were conducted using Microsoft Excel and Oracle® Crystal Ball (Figure 4).[66]

Monte Carlo analysis was conducted for six chemicals using concentration data for sediment, weathered oil, and tar. Datasets for body weight, frequency of exposure, and skin surface area from the BEACHES study, as well as chemical concentration data were used for the Monte Carlo analysis. A triangular distribution was assumed for each variable and minimum, likeliest, and maximum value was inputted to generate the distribution. Minimum represented the minimum value from each dataset; maximum represented the maximum value from each dataset; likeliest represented the median value from each dataset (Table 9). The simulation was run for 1,000 iterations. Risk range was generated for oral, dermal and inhalation exposure. Mean values for each exposure route are summarized in Table 12a for cancer risk and 10b for non-cancer risk.

A separate Monte Carlo analysis was run for 12 chemicals where the concentration data were known for sediment and weathered oil. There were no data on concentration in tar available for these 12 chemicals. The concentration value for sediment and weathered oil were used in the risk models as static values. Information for slope factor, RBA, and ABS for each chemical was taken from the Center for Environmental and Human Toxicology Technical Report (2005). The chemical-related data used in this analysis is summarized in Table 11. The same datasets for BW, SA, and F and distribution parameters from the BEACHES study were used for this analysis. A triangular distribution was assumed for each

dataset (Table 14). The simulation was run for 1,000 iterations. Risk range was generated for oral, dermal, and inhalation exposure. Mean values for each exposure route are summarized in Table 15a for cancer risk and 13b for non-cancer risk.

Protection of Human Subjects

Each participant was assigned an alphanumeric ID at check-in and this ID was used in all subsequent tests and records. The datasets will remain with the data owner (Dr. Solo-Gabriele, University of Miami) and all identifying information will be removed from the dataset before transfer to UTHealth.

Table 1: Input values for risk estimate comparison to data from Black et al. (2016).[61]

	Concentration (mg/kg)			Slope Factor				
Chemicals	**Sediment**	**Weathered Oil**	**Tar**	**Oral**	**Dermal**	**Inhalation**	**RBA Oral**	**ABS Dermal**
Arsenic	NM	39.4	BDL	1.5	1.579	15.05	0.5	0.01
Barium	NM	164	5.8	NA	NA	NA	0.5	0.01
Vanadium	77	25.5	0.2	NA	NA	NA	0.5	0.01
Benzo[a]pyrene	1.49	7.19	BDL	7.3	14.6	3.1	0.5	0.01
Benz[a]anthracene	1.91	33.9	BDL	0.73	1.46	0.31	0.5	0.01
Benzo[b]fluoranthene	1.46	4.4	0.62	0.73	1.46	0.31	0.5	0.01
Dibenz[a,h]anthracene	0.11	0.13	BDL	7.3	14.6	3.1	0.5	0.01

[1]

[1] Concentration values taken from post-DWH EPA sampling of shorelines. Data collection began on April 28th, 2010 and ended October 6, 2010. 14,434 samples of sediment, 6,363 samples of weathered oil, and 327 samples of tar were analyzed for metals and organic oil constituents.
Oral, dermal, and inhalation slope factor values, oral RBA, and dermal RBS were obtained from Center for Environmental Toxicology report (2005).[60]
NM = not measured
BDL = below detection limit
NA = not applicable
RBA = relative bioavailability
ABS = absorption factor

Table 2: Factors utilized for exposure assessment that are independent of chemicals considered.

Factor	Assumed Variables from Black et al. (2016)	Average Values from BEACHES Study
ALL PATHWAYS		
Body Weight, BW (kg)	25.4	37.5
Frequency of Exposure, F (days/year)	12	6.5
Exposure Duration, ED (years)	8	8
Average Time, AT (days)	365 (non-cancer) 28,489 (cancer)	365 (non-cancer) 28,489 (cancer)
Exposure Factor, EF (unitless)	0.263 (non-cancer) 0.002958 (cancer)	0.263 (non-cancer) 0.002958 (cancer)
ORAL		
Soil Intake Rate, IRS (mg/day)	1000	1000
Conversion Factor, CF (mg/kg)	0.000001	0.000001
DERMAL		
Skin Surface Area, SA (cm^2/event)	11,350	13,050.62
Adherence Factor, AD, AF (mg/cm^2)	18	18
Conversion Factor, CD, CF (mg/kg)	0.000001	0.000001
INHALATION		
Soil-to-Air Particulate Emission Factor, PEF (m^3/kg)	1,240,000,000	1,240,000,000
Inhalation Rate, IRa (m^3/day)	9.62	9.62
Exposure Time, ET (hours/day)	3	3

[2]

[2] Data taken from Black, et al. 2016.[57]

Table 3: Distribution of child participants used to create datasets for body weight and skin surface area.

	0 – 1 years (0-23 months)	**2 – 3 years (24-47 months)**	**4 – 6 years (48-73 months)**	**6+ years (72-83 months)**
Total Number	23	38	39	19
Male	10	21	18	5
Female	13	17	21	14
Percent	19.33	31.93	32.77	15.97
Average Body Weight (kg)	24.69	31.83	42.85	53.07
Average Skin Surface Area (cm^2)	9,220.60	11,700.27	14,655.13	17,094.21

[3]

[3] N = 391

Skin surface area was computed for each child participant using protocols from EPA Exposure Factors Handbook.[60]

Table 4: Distribution of survey responses used to create dataset for frequency of exposure.

	Number	Percent
Once a week	67	17.14
Once a month	142	36.32
Once a year	156	39.90
Uncertain	26	6.65

[4]

[4] N = 391
Respondents were asked “How often do you visit the beach?”

Table 5: Input values for chemical risk assessment.

	Concentration (mg/kg)			Slope Factor				
Chemicals	**Sediment**	**Weathered Oil**	**Tar**	**Oral**	**Dermal**	**Inhalation**	**RBA Oral**	**ABS Dermal**
Benzo[b]fluoranthene	0.06109	4.4	0.62	0.73	1.46	0.31	0.5	0.01
Benzo[e]pyrene	0.04733	4.285	0.75	7.3	14.6	3.1	0.5	0.01
C3-naphthalene	0.01094	2.30	0.70	0.02	$8.57x10^{-4}$	0.02	0.5	0.01
Chrysene	0.2417	26.86	4.8	0.0073	0.0146	0.0031	0.5	0.01
Fluoranthene	0.03597	2.169	61.0	0.04	0.02	0.02	0.5	0.01
Phenanthrene	0.1143	36.15	1.75	0.03	0.015	0.015	0.5	0.01

[5]

[5] Chemical concentration data were obtained from fate and transport modeling within the BEACHES study. Oral, dermal, and inhalation slope factor values, oral RBA, and dermal RBS were obtained from Center for Environmental Toxicology report (2005).[61]
The oral, dermal, and inhalation slope factor used for C3-naphthalene is that of naphthalene.
RBA = relative bioavailability
ABS = absorption factor

Figure 1: The risk assessment paradigm. Modified from the National Research Council Risk Assessment Framework.[67] Created using https://www.draw.io/.

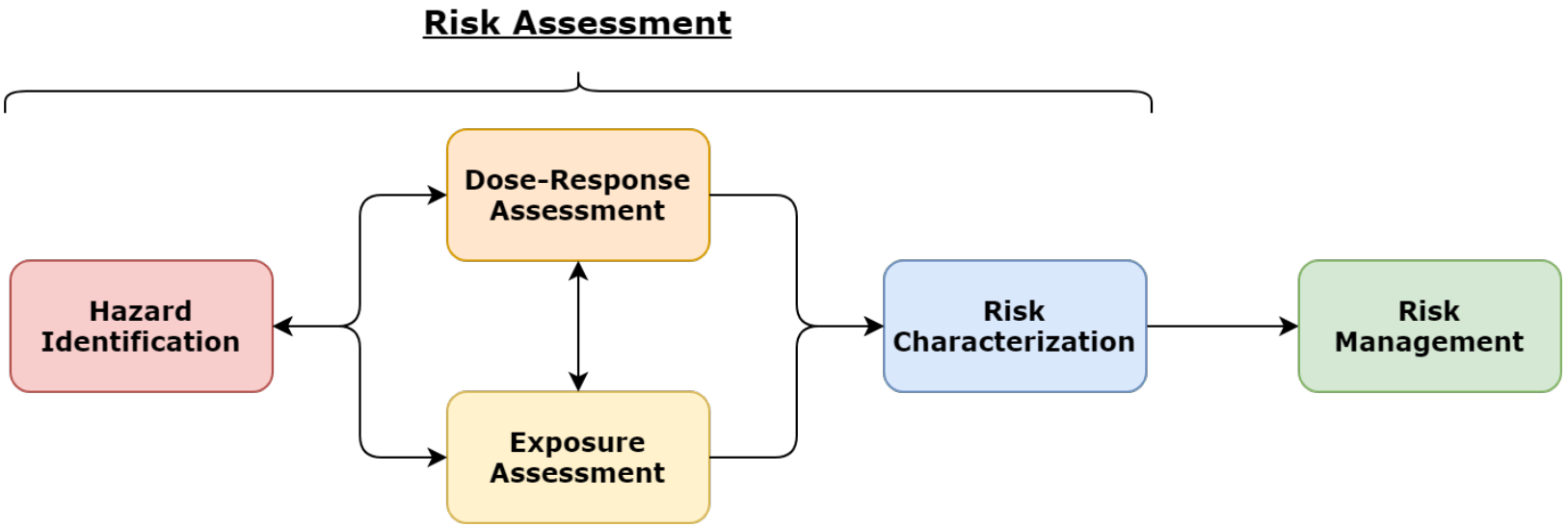


Figure 2: Locations of Haulover Beach (top) and Crandon Beach (bottom) in Miami, FL.

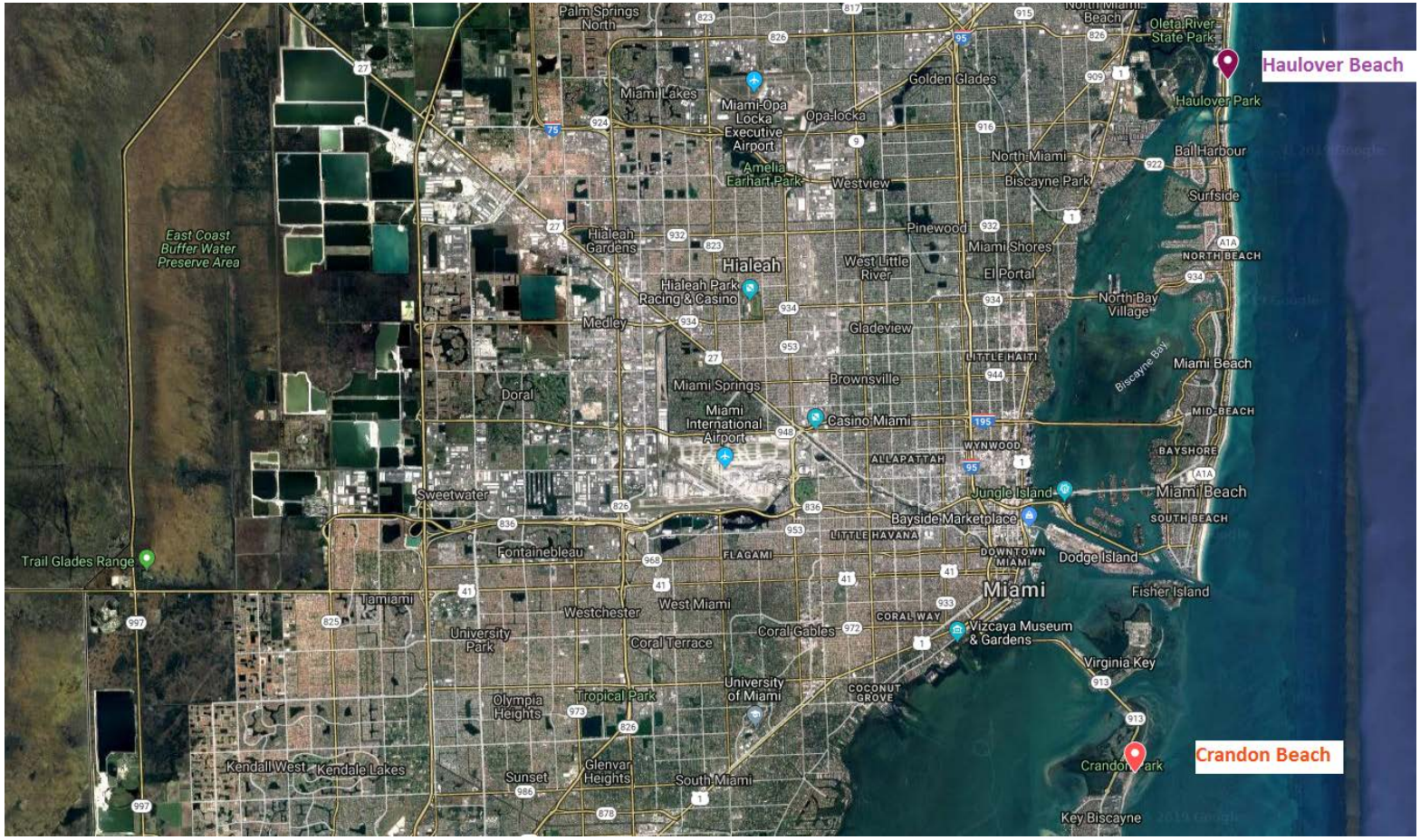
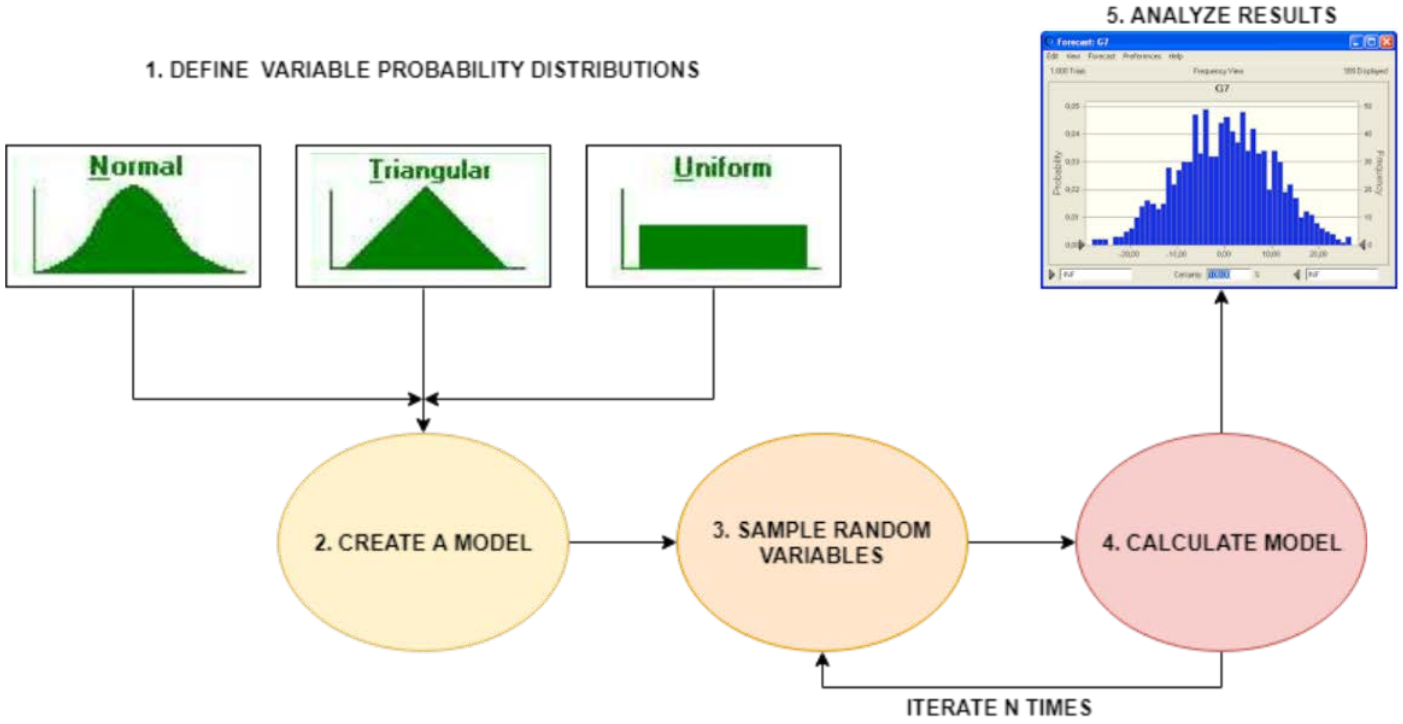


Figure 3: Locations of Seawall Beach (bottom) and Stewart Beach (top) in Galveston, TX.

Figure 4: Process of Monte Carlo simulation using Crystal Ball.[66] Created using https://www.draw.io/.



OBJECTIVE 1: HUMAN HEALTH RISK ASSESSMENT

Results

Comparison of BEACHES Risk Assessment to Black et al., 2016 Study

A prior human health risk assessment for children was conducted in 2016 by Black et al. using chemical concentration data from existing sampling (Table 1); exposure variables were modified from EPA Exposure Factors Handbook (Table 2).[64] Individual risk estimates for exposure to chemical concentrations in sediment, weathered oil, and tar (if measured) were added to provide single risk estimate per chemical, per exposure route. The results from this study were used as a baseline for this risk assessment process. A point estimate of risk was conducted using average values for body weight, frequency of exposure, and skin surface area generated from the BEACHES study and chemical concentration data used in the Black analysis. All other exposure variables were modified from the EPA Exposure Factors Handbook, consistent with the values used in the Black et al. analysis (Table 2).

The results from both point estimate risk assessments are summarized in Table 6a for cancer risk and Table 6b for non-cancer risk. There was a decrease of one order of magnitude of cancer risk estimate from the BEACHES study compared to the Black analysis for vanadium, benz[a]anthracene, and dibenz[a,h]anthracene in the oral exposure scenario. There was a decrease of one order of magnitude of cancer risk estimate from the BEACHES study compared to the Black analysis for benz[a]anthracene in the dermal exposure scenario. There was a decrease of one order of magnitude of cancer risk estimate from the BEACHES study compared to the Black analysis for dibenz[a,h]anthracene in the inhalation exposure scenario. All other comparisons only showed minor decrease in cancer risk estimate. Total

cumulative cancer risk estimates from oral ($2.04x10^{-05}$ vs. $5.57x10^{-05}$), dermal ($2.72x10^{-05}$ vs. $6.44x10^{-05}$) , and inhalation ($1.75x10^{-09}$ vs. $4.78x10^{-09}$) exposure routes from the BEACHES study did not differ significantly from cancer risk estimates from the Black analysis. There was a decrease of one order of magnitude of non-cancer risk estimate from the BEACHES study compared to the Black et al. analysis for barium, vanadium, benz[a]anthracene and benzo[b]fluoranthene in the oral exposure scenario. For dermal exposure, there was a decrease of one order of magnitude of non-cancer risk estimate from the BEACHES study compared to the Black et al. analysis for vanadium, benz[a]anthracene and benzo[b]fluoranthene. There was a decrease of one order of magnitude of non-cancer risk estimate from the BEACHES study compared to the Black et al. analysis for vanadium, benz[a]anthracene and dibenz[a,h]anthracene in the inhalation exposure scenario. All other comparisons showed only minor reductions in non-cancer risk estimates. Total cumulative non-cancer risk estimates from ($1.60x10^{-03}$ vs. $4.53x10^{-03}$), dermal ($2.12x10^{-03}$ vs. $5.03x10^{-03}$) , and inhalation ($1.37x10^{-07}$ vs. $3.73x10^{-07}$) exposure routes from the BEACHES study did not differ significantly from cancer risk estimates from the Black analysis. ***Risk Assessment Using BEACHES Chemical & Exposure Data***

A risk assessment was conducted using average variables for body weight, frequency of exposure, and skin surface area generated from the BEACHES study; all other variables were maintained from the previous analysis (Table 2). Six chemicals were chosen from chemical concentration data provided by a separate sub-project within the BEACHES study. These chemicals were chosen because concentration values for sediment, weathered oil, and tar were known. Chemical-specific variables were obtained from the Center for

Environmental Health and Technology Technical Report. Concentration and other chemical-specific values are summarized in Table 5. The results from the BEACHES risk assessment are summarized in Table 7a for cancer risk and Table 7b for non-cancer risk.

Cancer risk values from exposure to chemical concentrations in sediment, weathered oil, and tar from oral, dermal and inhalation exposure routes are summarized in Table 7a. Totals are given for each chemical (cumulative) and each exposure route (aggregate). Benzo[b]fluoranthene and benzo[e]pyrene show the highest cancer risk estimates of the six chemicals in this assessment for oral and dermal exposure routes in sediment. Benzo[e]pyrene shows the highest cancer risk estimate of the six chemicals in this assessment for oral and dermal exposure routes in weathered oil and tar. Benzo[e]pyrene shows the highest cancer risk estimate of the six chemicals in this assessment for inhalation exposure route in sediment and weathered oil. Benzo[e]pyrene and fluoranthene show the highest cancer risk estimate of the six chemicals in this assessment for inhalation exposure route in tar. Benzo[e]pyrene shows the highest total cancer risk estimate of the six chemicals in this assessment for all three exposure scenarios ($9.03x10^{-07}$ for oral, $8.48x10^{-06}$ for dermal, and $1.78x10^{-11}$ for inhalation route).

C3-naphthalene shows the lowest cancer risk estimate of the six chemicals in this assessment for oral exposure route in sediment and dermal exposure route in sediment, weathered oil, and tar. C3-naphthalene, chrysene, and fluoranthene show the lowest cancer risk estimate of the six chemicals in this assessment for oral and inhalation exposure routes in weathered oil. C3-naphthalene and chrysene show the lowest cancer risk estimate of the six chemicals in this assessment for oral exposure route in tar and inhalation exposure route in

sediment. C3-naphthalene, chrysene, and phenanthrene show the lowest cancer risk estimate of the six chemicals in this assessment for inhalation exposure route in tar. C3-naphthalene shows the lowest total cancer risk estimate of the six chemicals in this assessment for all three exposure routes ($1.47x10^{-09}$ for oral, $2.95x10^{-10}$ for dermal, and $6.82x10^{-14}$ for inhalation route).

Total cumulative cancer risk estimates in sediment, weathered oil, and tar from oral, dermal, and inhalation exposure are also presented. Total risk estimates are highest in oral and dermal exposure routes and lowest in inhalation exposure route. There is a difference of three orders of magnitude between total risk estimates from inhalation exposure compared to oral and dermal exposure. Total risk estimates are highest in weathered oil and tar and lowest in sediment for oral and dermal exposure routes. Total risk estimates are highest in weathered oil and lowest in sediment for inhalation exposure routes.

Non-cancer risk values from exposure to chemical concentrations in sediment, weathered oil, and tar from oral, dermal, and inhalation exposure routes are summarized in Table 7b. Totals are given for each chemical (cumulative) and each exposure route (aggregate). Benzo[e]pyrene shows the highest non-cancer risk estimate of the six chemicals in this assessment for oral exposure routes in sediment, weathered oil, and tar. Benzo[e]pyrene shows the highest non-cancer risk estimate of the six chemicals in this assessment for dermal and inhalation exposure routes in sediment and weathered oil. Benzo[e]pyrene and fluoranthene show the highest non-cancer risk estimate of the six chemicals in this assessment for dermal and inhalation exposure routes in tar. Benzo[e]pyrene shows the highest total non-cancer risk estimate of the six chemicals in this

assessment for all three exposure routes ($7.05x10^{-05}$ for oral, $6.62x10^{-04}$ for dermal, and $1.39x10^{-09}$ for inhalation route).

C3-naphthalene shows the lowest non-cancer risk estimate of the six chemicals in this assessment for oral exposure route in sediment and weathered oil, and dermal exposure route in sediment, weathered oil and tar. C3-naphthalene, chrysene, and phenanthrene show the lowest non-cancer risk estimate of the six chemicals in this assessment for oral and inhalation exposure routes in tar. C3-naphthalene and chrysene show the lowest non-cancer risk estimate of the six chemicals in this assessment for inhalation exposure route in sediment. C3-naphthalene, chrysene, and fluoranthene show the lowest non-cancer risk estimate of the six chemicals in this assessment for inhalation exposure route in weathered oil. C3-naphthalene shows the lowest total non-cancer risk estimate for oral, dermal, and inhalation exposure routes ($1.14x10^{-07}$ for oral, $2.30x10^{-08}$ for dermal, and $5.32x10^{-12}$ for inhalation route).

Total cumulative non-cancer risk estimates in sediment, weathered oil, and tar from oral, dermal, and inhalation exposure are also presented. Total non-cancer risk estimates are highest in dermal exposure route and lowest in inhalation exposure route. There is a difference of three orders of magnitude between total non-cancer risk estimates from inhalation exposure compared to dermal exposure. There is a difference of two orders of magnitude between total non-cancer risk estimates from inhalation exposure compared to oral exposure. Total non-cancer risk estimates are highest in weathered oil and tar and lowest in sediment for oral and dermal exposure routes. Total non-cancer risk estimates are highest in weathered oil and lowest in sediment for inhalation exposure routes.

Table 6a. Comparison of cancer risk estimate values from oral, dermal and inhalation exposure for seven chemicals between risk assessment conducted by Black et al. (2016) and data generated from the BEACHES study.

Cancer	**Oral**		**Dermal**		**Inhalation**	
CHEMICAL	Black	BEACHES	Black	BEACHES	Black	BEACHES
Arsenic	5.13E-06	1.88E-06	3.34E-06	1.41E-06	3.63E-09	1.33E-09
Barium	3.06E-05	1.12E-05	6.25E-06	2.64E-06	7.12E-10	2.61E-10
Vanadium	1.36E-05	5.00E-06	2.78E-06	1.17E-06	3.17E-10	1.16E-10
Benzo(a)pyrene	4.20E-06	1.54E-06	3.43E-05	1.45E-05	8.31E-11	3.05E-11
Benz(a)anthracene	1.73E-06	6.36E-07	1.42E-05	5.98E-06	3.43E-11	1.26E-11
Benzo(b)fluoranthene	3.14E-07	1.15E-07	2.56E-06	1.08E-06	6.20E-12	2.28E-12
Dibenz[a,h]anthracene	1.16E-07	4.26E-08	9.50E-07	4.01E-07	2.30E-12	8.43E-13
TOTAL	**5.57E-05**	**2.04E-05**	**6.44E-05**	**2.72E-05**	**4.78E-09**	**1.75E-09**

Table 6b. Comparison of non-cancer risk estimates for oral, dermal and inhalation exposure for seven chemicals from the Black et al. (2016) study and the BEACHES study.

Non-Cancer	**Oral**		**Dermal**		**Inhalation**	
CHEMICAL	Black	BEACHES	Black	BEACHES	Black	BEACHES
Arsenic	4.00E-04	1.47E-04	2.61E-04	1.10E-04	2.83E-07	1.04E-07
Barium	2.39E-03	8.76E-04	4.88E-04	2.06E-04	5.56E-08	2.04E-08
Vanadium	1.06E-03	3.90E-04	2.17E-04	9.17E-05	2.48E-08	9.08E-09
Benzo(a)pyrene	3.28E-04	1.20E-04	2.68E-03	1.13E-03	6.48E-09	2.38E-09
Benz(a)anthracene	1.35E-04	4.97E-05	1.11E-03	4.67E-04	2.68E-09	9.82E-10
Benzo(b)fluoranthene	2.45E-05	8.99E-06	2.00E-04	8.44E-05	4.84E-10	1.78E-10
Dibenz[a,h]anthracene	9.07E-06	3.33E-06	7.41E-05	3.13E-05	1.79E-10	6.58E-11
TOTAL	**4.35E-03**	**1.60E-03**	**5.03E-03**	**2.12E-03**	**3.73E-07**	**1.37E-07**

Table 7a. Point estimate cancer risk estimates from oral, dermal and inhalation exposure for six chemicals in sediment, weathered oil, and tar.

Chemical	Oral				Dermal				Inhalation				Total
	Sediment	Weathered Oil	Tar	Total	Sediment	Weathered Oil	Tar	Total	Sediment	Weathered Oil	Tar	Total	
Benzo[b]fluoranthene	1.09E-09	7.82E-08	1.10E-08	9.03E-08	1.02E-08	7.35E-07	1.04E-07	8.48E-07	2.15E-14	1.55E-12	2.18E-13	1.78E-12	1.09E-09
Benzo[e]pyrene	8.41E-09	7.61E-07	1.33E-07	9.03E-07	7.90E-08	7.15E-06	1.25E-06	8.48E-06	1.66E-13	1.50E-11	2.63E-12	1.78E-11	8.41E-09
C3-Naphthalene	5.32E-12	1.12E-09	3.41E-10	1.47E-09	1.07E-12	2.25E-10	6.86E-11	2.95E-10	2.48E-16	5.21E-14	1.59E-14	6.82E-14	5.32E-12
Chrysene	4.29E-11	4.77E-09	8.53E-10	5.67E-09	4.03E-10	4.48E-08	8.01E-09	5.33E-08	8.49E-16	9.43E-14	1.69E-14	1.12E-13	4.29E-11
Fluoranthene	3.50E-10	2.11E-09	5.94E-08	6.18E-08	8.23E-10	4.96E-09	1.39E-07	1.45E-07	8.15E-15	4.91E-14	1.38E-12	1.44E-12	3.50E-10
Phenanthrene	8.35E-11	2.64E-08	1.28E-09	2.78E-08	1.96E-10	6.20E-08	3.00E-09	6.52E-08	1.94E-15	6.14E-13	2.97E-14	6.46E-13	8.35E-11
Total	9.98E-09	8.74E-07	2.06E-07	1.09E-06	9.06E-08	8.00E-06	1.51E-06	9.60E-06	1.99E-13	1.74E-11	4.30E-12	2.19E-11	9.98E-09

6

[6] Computed averages for body weight, frequency of exposure, and skin surface area were generated from BEACHES data. Chemical concentration data were obtained from fate and transport modeling within the BEACHES study.

Table 7b. Point estimate non-cancer risk estimates from oral, dermal and inhalation exposure for six chemicals in sediment, weathered oil, and tar.

Chemical	Oral				Dermal				Inhalation				Total
	Sediment	Weathered Oil	Tar	Total	Sediment	Weathered Oil	Tar	Total	Sediment	Weathered Oil	Tar	Total	
Benzo[b]fluoranthene	8.47E-08	6.10E-06	8.60E-07	7.05E-06	7.96E-07	5.73E-05	8.08E-06	6.62E-05	1.67E-12	1.21E-10	1.70E-11	1.39E-10	8.47E-08
Benzo[e]pyrene	6.56E-07	5.94E-05	1.04E-05	7.05E-05	6.17E-06	5.58E-04	9.77E-05	6.62E-04	1.30E-11	1.17E-09	2.06E-10	1.39E-09	6.56E-07
C3-Naphthalene	4.16E-10	8.74E-08	2.66E-08	1.14E-07	8.37E-11	1.76E-08	5.35E-09	2.30E-08	1.93E-14	4.07E-12	1.24E-12	5.32E-12	4.16E-10
Chrysene	3.35E-09	3.72E-07	6.66E-08	4.42E-07	3.15E-08	3.50E-06	6.25E-07	4.16E-06	6.63E-14	7.36E-12	1.32E-12	8.74E-12	3.35E-09
Fluoranthene	2.73E-08	1.65E-07	4.63E-06	4.83E-06	6.42E-08	3.87E-07	1.09E-05	1.13E-05	6.36E-13	3.84E-12	1.08E-10	1.12E-10	2.73E-08
Phenanthrene	6.51E-09	2.06E-06	9.97E-08	2.17E-06	1.53E-08	4.84E-06	2.34E-07	5.09E-06	1.52E-13	4.79E-11	2.32E-12	5.04E-11	6.51E-09
Total	7.79E-07	6.82E-05	1.61E-05	8.51E-05	7.07E-06	6.24E-04	1.18E-04	7.49E-04	1.55E-11	1.36E-09	3.35E-10	1.71E-09	7.79E-07

[7]

[7] Computed averages for body weight, frequency of exposure, and skin surface area were generated from BEACHES data. Chemical concentration data were obtained from fate and transport modeling within the BEACHES study.

Discussion

There is existing literature characterizing the health risks to adults from exposure to OSCs, however analyses specific to children's health risks are limited. Children are considered a vulnerable population; studying children's health risks is complex and involves many factors, such as a child's rapid growth, physical and cognitive development, and varied and age-related behaviors that may influence the types and magnitude of exposure to various contaminants.[62] The normal steps to process a substance within the body – absorption, distribution, metabolism and clearance – are less developed in children, which can result in greater risk for adverse health outcomes compared to adults.[63] These parameters can change dramatically among infants, toddlers, and older children.[62] For example, indiscriminate ingestion and crawling behavior among young children can put them at risk of exposure to certain hazards.[63] In the beach environment, young children spend a majority of their play time in the sand and intertidal zone, where chemical contaminants tend to accrue. Whereas normally the primary exposure route of focus for children's health in outdoor environments is inhalation exposure, the combination of crawling, non-dietary ingestion, and potential contamination of beach sand broaden the scope of potential health risks to children.[57] Most existing risk assessment analyses are based on adult exposure, either using data from mature animal models, or from studies in the occupational environment. The rare exception is in cases where the health outcome is related to growth and development.[62]

For this human health risk assessment, a point risk estimate analysis was conducted using variables generated from the BEACHES study and compared against a prior children's health risk assessment by Black et al. (2016).[57] The variables for body weight and skin

surface area were collected from 119 height and weight measurements of children who successfully completed the study, and frequency of exposure was modified from 391 completed parental surveys. This prior risk assessment utilized values from the EPA Exposure Factors Handbook, which averaged values for children between the ages of 2 to 10. Compared to the standard value established by the EPA Exposure Factors Handbook (for children aged 2 to 10), average body weight from the BEACHES study was slightly higher at 37.5 versus 25.4 kg for children between walking and 6 years of age. Average skin surface area was also higher in the BEACHES cohort, 13,050, versus 11,350 cm^2.[59] Average self-reported frequency of exposure was lower compared to the value used in the Black et al. analysis (6.5 versus 12 days per year visits to the beach). Children who qualified to participate in the BEACHES study were required to meet two criteria: they can walk unaided, and were under the age of 7. Almost half (48.74%) of the children who completed the BEACHES study were above the age of four; only one child was under one year of age. Since the overall demographic profile of children in the BEACHES study skewed toward the older, this accounts for the higher average body weight and skin surface area values compared to EPA established standard values.

The three equations used as models for cancer and non-cancer risk from oral, dermal and inhalation exposure to OSCs use multiplication and division as the primary method for manipulating risk inputs. Mathematically, a change by one order of magnitude will change the risk output value by one order of magnitude. Compared to the standard values used in the Black analysis, the average BEACHES variables were lower in two cases: frequency of exposure (45.8% decrease) and body weight (47.6% decrease). Average body weight was

higher in the BEACHES cohort (47.6% increase), but since body weight is found in the denominator of each of the risk equations, it can be assumed that this is actually a 47.6% decrease mathematically. The average value for skin surface area from the BEACHES study was higher than the average value used in the Black analysis (15% increase). Since two out of three variables reduce the overall output, and the remaining variable is only used in one equation (risk from dermal exposure), it is logical that the risk estimates from the BEACHES study will be lower compared to the Black analysis. Based on the results, the risk estimates from the BEACHES study were lower than in the Black analysis in every case. In some cases, the risk estimate was lower by one order of magnitude: for cancer risk, risk estimates differed by one order of magnitude for three chemicals in oral exposure scenario, one chemical in dermal exposure scenario, and three chemicals in inhalation exposure scenario; for non-cancer risk, risk estimates differed by one order of magnitude for four chemicals in oral exposure scenario, three chemical in dermal exposure scenario, and three chemicals in inhalation exposure scenario. Risk estimates from dermal exposure showed the least amount of change compared to the Black analysis, likely due to the value used for skin surface area offsetting reductions from smaller values used for average body weight and frequency of exposure. In both risk assessments, the lowest risk estimates were seen in inhalation exposure and highest risk estimates were seen in oral and dermal exposure. This suggests that the latter two exposure routes should be of greatest concern when evaluating and communicating children's health risks in the beach environment.

A separate risk assessment was conducted using chemical information from a project within the BEACHES study. Six chemicals were selected from a larger dataset due to

existing shoreline chemical concentration information for sediment, weathered oil, and tar. Following DWH oil spill, approximately 22% of oil that was released deposited onto shoreline sediment or was carried to shorelines as tar.[64] Weathered oil is used in this risk assessment to represent the upper limit of OSC concentration that can exist in sediment following shoreline oiling.[57] Chemical-specific variables for slope factor, oral relative bioavailability factor, and absorption factor were extracted from the same source as the chemicals used in the comparative analysis (CEHT 2005). Highest risk estimates were observed using concentrations from weathered oil and tar; using these concentrations allows for a conservative risk estimation, since it is unlikely that concentrations will be found significantly higher than these values. Similar to the comparative analysis, risk estimates for inhalation exposure were considerably lower compared to risk estimates from oral and dermal exposure. This suggests that communications regarding children's health risks to families following an oil spill event should focus on oral and dermal exposure scenarios. This translates to proper hygiene practices during and following beach play – limiting ingestion or mouthing of objects that are covered in sand, and thoroughly cleaning sand and water from the child's skin. In all three cases, overall risk estimates were relatively low; however, this assessment only accounts for six OSCs; crude oil contains hundreds of compounds, and additional chemical by-products are created when crude oil comes into contact and reacts with water and air.[65]

OBJECTIVE 2: SENSITIVITY AND MONTE CARLO ANALYSIS

Results

Sensitivity Analysis

Mean, 2.5% and 97.5% percentile total risk values (aggregate risk from oral, dermal and inhalation exposure routes) are summarized in Tables 8a, 9a, 10a, 11a, 12a and 13a for cancer outcomes and Tables 8b, 9b, 10b, 11b, 12b and 13b for non-cancer outcomes.

Mean total risk values for benzo[b]fluoranthene increased by one order of magnitude for Trial 4 (varying frequency of exposure) and Trial 6 (varying all four datasets in both cancer and non-cancer calculations). No change in either direction was observed for Trial 2: varying body weight, Trial 3: varying skin surface area, or Trial 5: varying chemical concentration. The same order of magnitude increase was seen in mean risk values for Trial 4 and Trial 6 for C3-naphthalenes, chrysene and phenanthrene for both cancer and non-cancer outcomes. No change in either direction was observed for Trial 2, Trial 3 and Trial 5 for C3-naphthalenes, chrysene and phenanthrene for both cancer and non-cancer calculations.

Mean total risk values for benzo[e]pyrene decreased by one order of magnitude for Trial 2 and Trial 5 in cancer calculations. No change in either direction was observed for Trial 3, Trial 4 or Trial 6 in cancer calculations. Mean total risk values for benzo[e]pyrene increased by one order of magnitude for Trial 4 and Trial 6 in non-cancer calculations. No change in either direction was observed for Trial 2, Trial 3 or Trial 5 in non-cancer estimations.

Mean total risk values for fluoranthene increased by one order of magnitude for Trial 6 in cancer calculations. No change in either direction was observed for Trial 2, Trial 3, Trial

4, and Trial 5 for fluoranthene for cancer calculations. Mean total risk values for fluoranthene increased by one order of magnitude for Trial 6 in non-cancer calculations. No change in either direction was observed for Trial 3, Trial 4, or Trial 5 in non-cancer calculations. Mean total risk value for fluoranthene decreased by one order of magnitude for Trial 2 in non-cancer calculations.

Monte Carlo Analysis for 6 Chemicals

Cancer

Mean risk values associated with oral, dermal and inhalation exposure routes are summarized in Table 15a for cancer outcomes. Benzo[e]pyrene shows the highest risk estimate of the six chemicals in this assessment for oral and dermal exposure routes. Benzo[e]pyrene, C3-naphthalenes and phenanthrene show the highest risk estimate of the six chemicals assessed for inhalation exposure. Chrysene and fluoranthene show the lowest risk estimate of the six chemicals in this assessment for oral and inhalation exposure. Fluoranthene shows the lowest risk estimate of the six chemicals assessed in for dermal exposure.

Total oral, dermal and inhalation cumulative risk are also presented. Total risk estimates are highest for dermal exposure route ($2.88x10^{-05}$) and lowest for inhalation exposure route ($1.11x10^{-16}$). There is a difference of 11 orders of magnitude between total risk estimates from inhalation exposure compared to dermal exposure. In addition, there is a difference of 10 orders of magnitude between total risk estimates from inhalation exposure compared to oral exposure ($4.13\ x10^{-06}$). Further, there is a difference of one order of magnitude between total risk estimates from oral exposure compared to dermal exposure.

Non-Cancer

Mean risk values from oral, dermal and inhalation exposure routes are summarized in Table 15b for non-cancer outcomes. Benzo[e]pyrene shows the highest risk estimate of the six chemicals in this assessment for oral and dermal exposure routes. Benzo[e]pyrene, C3-naphthalenes, and phenanthrene show the highest risk estimate of the six chemicals assessed for inhalation exposure. Chrysene and fluoranthene show the lowest risk estimate of the six chemicals in this assessment for oral and inhalation exposure. Fluoranthene shows the lowest risk estimate of the six chemicals assessed in for dermal exposure.

Total oral, dermal and inhalation cumulative risk are also presented. Total risk estimates are highest in dermal exposure route (2.25×10^{-03}) and lowest in inhalation exposure route (8.58×10^{-15}). There is a difference of 12 orders of magnitude between total risk estimates from inhalation exposure compared to dermal exposure. There is a difference of 11 orders of magnitude between total risk estimates from inhalation exposure compared to oral exposure (3.21×10^{-04}). There is a difference of one order of magnitude between total risk estimates from oral exposure compared to dermal exposure.

Monte Carlo Analysis for 12 Chemicals

A separate Monte Carlo analysis was conducted for 12 OSCs due to missing information for chemical concentration in tar. Mean risk values from oral, dermal and inhalation exposure routes using concentration values from sediment and weathered oil are summarized in Table 18a for cancer outcomes and 16b for non-cancer outcomes.

Cancer

Of the twelve chemicals in this assessment, benzo[a]pyrene shows the highest cancer risk estimate for oral and dermal exposure routes in both sediment ($2.19x10^{-08}$ and $1.51x10^{-06}$, respectively and weathered oil ($2.14x10^{-07}$ and $1.48\ x10^{-05}$, respectively). Benzo[a]pyrene show the highest cancer risk estimate for inhalation exposure in weathered oil, and both benzo[a]pyrene and dibenz[a,h]anthracene show the highest cancer risk estimate for inhalation exposure in sediment. Of the twelve chemicals in this assessment, acenaphthene, acenaphthylene, benzo[g,h,i]perylene, fluorene, naphthalene and pyrene show the lowest cancer risk estimate for oral exposure in sediment. Acenaphthylene and naphthalene show the lowest cancer risk estimate for oral exposure in weathered oil. Naphthalene is associated with the lowest cancer risk estimate for dermal exposure in both sediment and weathered oil. Acenaphthylene and naphthalene show the lowest cancer risk estimates for inhalation exposure in sediment, and acenaphthylene relates to the lowest cancer risk estimate for inhalation exposure in weathered oil.

Total oral, dermal, and inhalation cumulative cancer risk are also presented (Table 18a). Total cancer risk estimates are highest in weathered oil for all three exposure routes. Total cancer risk estimates are highest in dermal exposure route and lowest in inhalation exposure route. There is a difference of 12 orders of magnitude between total cancer risk estimates from inhalation exposure compared to dermal exposure. There is a difference of 11 orders of magnitude between total cancer risk estimates from inhalation exposure compared to oral exposure. There is a difference of one order of magnitude between total cancer risk estimates from oral exposure compared to dermal exposure.

Non-Cancer

Mean risk values from oral, dermal and inhalation exposure routes using concentration values from sediment and weathered oil are summarized in Table 18b for non-cancer outcomes.

Of the twelve chemicals in this assessment, benzo[a]pyrene shows the highest non-cancer risk estimate for oral and dermal exposure routes in both sediment and weathered oil. Benzo[a]pyrene showed the highest non-cancer risk estimate for inhalation exposure in weathered oil, and both benzo[a]pyrene and dibenz[a,h]anthracene show the highest non-cancer risk estimate for inhalation exposure in sediment. Of the twelve chemicals in this assessment, acenaphthylene and naphthalene show the lowest non-cancer risk estimates for oral exposure in sediment and weathered oil. Naphthalene shows the lowest non-cancer risk estimate for dermal exposure in both sediment and weathered oil. Acenaphthene, acenaphthylene, benzo[g,h,i]perylene, and naphthalene show the lowest non-cancer risk estimate for inhalation exposure in sediment acenaphthylene shows the lowest non-cancer risk estimate for inhalation exposure in weathered oil.

Total oral, dermal and inhalation cumulative non-cancer risk are also presented (Table 18b). Total non-cancer risk estimates are highest in weathered oil for all three exposure routes. Total non-cancer risk estimates are highest in dermal exposure route and lowest in inhalation exposure route. There is a difference of 12 orders of magnitude between total non-cancer risk estimates from inhalation exposure compared to dermal exposure. There is a difference of 11 orders of magnitude between total non-cancer risk estimates from inhalation exposure compared to oral exposure. There is a difference of one order of

magnitude between total non-cancer risk estimates from oral exposure compared to dermal exposure.

Table 8a. Cancer risk estimates for benzo[b]fluoranthene based on varying datasets.

	Inputs				Simulation Output		
Trial	**Body Weight (kg)**	**Skin Surface Area (cm2)**	**Frequency (days/yr)**	**Concentration (mg/kg)**	**Mean**	**Value (2.5%)**	**Value (97.5%)**
1	34.8	12582	3	6.07	**5.40E-07**	NA	NA
2	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	12582	3	6.07	4.37E-07	2.69E-07	7.24E-07
3	34.8	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	3	6.07	5.75E-07	3.89E-07	8.13E-07
4	34.8	12582	**Min: 1 Likeliest: 3 Max: 50**	6.07	2.69E-06	6.31E-07	7.24E-06
5	34.8	12582	3	**Min: 0.007211 Likeliest: 6.07 Max: 23.36**	7.76E-07	2.14E-07	1.74E-06
6	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	**Min: 1 Likeliest: 3 Max: 50**	**Min: 0.007211 Likeliest: 6.07 Max: 23.36**	3.31E-06	6.03E-07	1.62E-05

[8]

[8] Trial 1 = risk assessment estimate using average values computed from BEACHES data.
Trial 2 = risk assessment estimate using full dataset for body weight and averages for all other variables.
Trial 3 = risk assessment estimate using full dataset for skin surface area and averages for all other variables.
Trial 4 = risk assessment estimate using full dataset for frequency of exposure and averages for all other variables.
Trial 5 = risk assessment estimate using full dataset for chemical concentration and averages for all other variables.
Trial 6 = risk assessment estimate using full dataset for body weight, skin surface area, frequency of exposure, and chemical concentration.

Table 8b. Non-cancer risk estimates for benzo[b]fluoranthene based on varying datasets.

	Inputs				Simulation Output		
Trial	**Body Weight (kg)**	**Skin Surface Area (cm2)**	**Frequency (days/yr)**	**Concentration (mg/kg)**	**Mean**	**Value (2.5%)**	**Value (97.5%)**
1	34.8	12582	3	6.07	4.21E-05	NA	NA
2	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	12582	3	6.07	3.39E-05	2.09E-05	7.24E-05
3	34.8	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	3	6.07	4.47E-05	3.09E-05	6.31E-05
4	34.8	12582	**Min: 1 Likeliest: 3 Max: 50**	6.07	2.14E-04	4.90E-05	5.62E-04
5	34.8	12582	3	**Min: 0.007211 Likeliest: 6.07 Max: 23.36**	6.03E-05	1.66E-05	1.38E-04
6	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	**Min: 1 Likeliest: 3 Max: 50**	**Min: 0.007211 Likeliest: 6.07 Max: 23.36**	2.75E-04	4.68E-05	1.26E-03

[9]

[9] Trial 1 = risk assessment estimate using average values computed from BEACHES data.
Trial 2 = risk assessment estimate using full dataset for body weight and averages for all other variables.
Trial 3 = risk assessment estimate using full dataset for skin surface area and averages for all other variables.
Trial 4 = risk assessment estimate using full dataset for frequency of exposure and averages for all other variables.
Trial 5 = risk assessment estimate using full dataset for chemical concentration and averages for all other variables.
Trial 6 = risk assessment estimate using full dataset for body weight, skin surface area, frequency of exposure, and chemical concentration.

Table 9a. Cancer risk estimates for benzo[e]pyrene based on varying datasets.

	Inputs				Simulation Output		
Trial	**Body Weight (kg)**	**Skin Surface Area (cm2)**	**Frequency (days/yr)**	**Concentration (mg/kg)**	**Mean**	**Value (2.5%)**	**Value (97.5%)**
1	34.8	12582	3	12.12	1.08E-05	NA	NA
2	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	12582	3	12.12	8.71E-06	5.50E-06	1.48E-05
3	34.8	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	3	12.12	1.15E-05	7.94E-06	1.62E-05
4	34.8	12582	**Min: 1 Likeliest: 3 Max: 50**	12.12	5.25E-05	1.26E-05	1.41E-04
5	34.8	12582	3	**Min: 0.0038 Likeliest: 12.12 Max: 13.05**	6.92E-06	2.09E-06	1.10E-05
6	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	**Min: 1 Likeliest: 3 Max: 50**	**Min: 0.0038 Likeliest: 12.12 Max: 13.05**	2.82E-05	4.79E-06	1.32E-04

10

[10]Trial 1 = risk assessment estimate using average values computed from BEACHES data.
Trial 2 = risk assessment estimate using full dataset for body weight and averages for all other variables.
Trial 3 = risk assessment estimate using full dataset for skin surface area and averages for all other variables.
Trial 4 = risk assessment estimate using full dataset for frequency of exposure and averages for all other variables.
Trial 5 = risk assessment estimate using full dataset for chemical concentration and averages for all other variables.
Trial 6 = risk assessment estimate using full dataset for body weight, skin surface area, frequency of exposure, and chemical concentration.

Table 9b. Non-cancer risk estimates for benzo[e]pyrene based on varying datasets.

	Inputs				Simulation Output		
Trial	**Body Weight (kg)**	**Skin Surface Area (cm2)**	**Frequency (days/yr)**	**Concentration (mg/kg)**	**Mean**	**Value (2.5%)**	**Value (97.5%)**
1	34.8	12582	3	12.12	8.41E-04	NA	NA
2	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	12582	3	12.12	6.92E-04	4.27E-04	1.05E-03
3	34.8	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	3	12.12	8.91E-04	6.17E-04	1.26E-03
4	34.8	12582	**Min: 1 Likeliest: 3 Max: 50**	12.12	4.07E-03	1.00E-03	1.10E-02
5	34.8	12582	3	**Min: 0.0038 Likeliest: 12.12 Max: 13.05**	5.37E-04	1.66E-04	3.72E-04
6	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	**Min: 1 Likeliest: 3 Max: 50**	**Min: 0.0038 Likeliest: 12.12 Max: 13.05**	2.19E-03	3.72E-04	1.02E-02

[11]

[11] Trial 1 = risk assessment estimate using average values computed from BEACHES data.
Trial 2 = risk assessment estimate using full dataset for body weight and averages for all other variables.
Trial 3 = risk assessment estimate using full dataset for skin surface area and averages for all other variables.
Trial 4 = risk assessment estimate using full dataset for frequency of exposure and averages for all other variables.
Trial 5 = risk assessment estimate using full dataset for chemical concentration and averages for all other variables.
Trial 6 = risk assessment estimate using full dataset for body weight, skin surface area, frequency of exposure, and chemical concentration.

Table 10a. Cancer risk estimates for C3-naphthalene based on varying datasets.

	Inputs				Simulation Output		
Trial	**Body Weight (kg)**	**Skin Surface Area (cm2)**	**Frequency (days/yr)**	**Concentration (mg/kg)**	**Mean**	**Value (2.5%)**	**Value (97.5%)**
1	34.8	12582	3	1167.35	3.37E-07	NA	NA
2	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	12582	3	1167.35	2.69E-07	1.74E-07	4.57E-07
3	34.8	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	3	1167.35	3.39E-07	3.24E-07	3.63E-07
4	34.8	12582	**Min: 1 Likeliest: 3 Max: 50**	1167.35	1.74E-06	4.37E-07	4.27E-06
5	34.8	12582	3	**Min: 0.01094 Likeliest: 1616.11 Max: 1858.97**	3.16E-07	1.32E-07	4.90E-07
6	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	**Min: 1 Likeliest: 3 Max: 50**	**Min: 0.01094 Likeliest: 1616.11 Max: 1858.97**	1.29E-06	2.63E-07	5.01E-06

[12]

[12] Trial 1 = risk assessment estimate using average values computed from BEACHES data.
Trial 2 = risk assessment estimate using full dataset for body weight and averages for all other variables.
Trial 3 = risk assessment estimate using full dataset for skin surface area and averages for all other variables.
Trial 4 = risk assessment estimate using full dataset for frequency of exposure and averages for all other variables.
Trial 5 = risk assessment estimate using full dataset for chemical concentration and averages for all other variables.
Trial 6 = risk assessment estimate using full dataset for body weight, skin surface area, frequency of exposure, and chemical concentration.

Table 10b. Non-cancer risk estimates for C3-naphthalene based on varying datasets.

	Inputs				Simulation Output		
Trial	**Body Weight (kg)**	**Skin Surface Area (cm2)**	**Frequency (days/yr)**	**Concentration (mg/kg)**	**Mean**	**Value (2.5%)**	**Value (97.5%)**
1	34.8	12582	3	1167.35	2.63E-05	NA	NA
2	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	12582	3	1167.35	2.09E-05	1.35E-05	3.55E-05
3	34.8	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	3	1167.35	2.69E-05	2.51E-05	2.88E-05
4	34.8	12582	**Min: 1 Likeliest: 3 Max: 50**	1167.35	1.35E-04	3.39E-05	3.31E-04
5	34.8	12582	3	**Min: 0.01094 Likeliest: 1616.11 Max: 1858.97**	2.45E-05	1.02E-05	3.80E-05
6	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	**Min: 1 Likeliest: 3 Max: 50**	**Min: 0.01094 Likeliest: 1616.11 Max: 1858.97**	1.02E-04	2.09E-05	3.89E-04

[13]

[13] Trial 1 = risk assessment estimate using average values computed from BEACHES data.
Trial 2 = risk assessment estimate using full dataset for body weight and averages for all other variables.
Trial 3 = risk assessment estimate using full dataset for skin surface area and averages for all other variables.
Trial 4 = risk assessment estimate using full dataset for frequency of exposure and averages for all other variables.
Trial 5 = risk assessment estimate using full dataset for chemical concentration and averages for all other variables.
Trial 6 = risk assessment estimate using full dataset for body weight, skin surface area, frequency of exposure, and chemical concentration.

Table 11a. Cancer risk estimates for chrysene based on varying datasets.

	Inputs				Simulation Output		
Trial	**Body Weight (kg)**	**Skin Surface Area (cm2)**	**Frequency (days/yr)**	**Concentration (mg/kg)**	**Mean**	**Value (2.5%)**	**Value (97.5%)**
1	34.8	12582	3	49.71	4.42E-08	NA	NA
2	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	12582	3	49.71	3.55E-08	2.24E-08	6.03E-08
3	34.8	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	3	49.71	4.68E-08	3.24E-08	6.61E-08
4	34.8	12582	**Min: 1 Likeliest: 3 Max: 50**	49.71	2.24E-07	5.50E-08	5.89E-07
5	34.8	12582	3	**Min: 0.011175 Likeliest: 49.71 Max: 231.38**	7.24E-08	2.24E-08	1.66E-07
6	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	**Min: 1 Likeliest: 3 Max: 50**	**Min: 0.011175 Likeliest: 49.71 Max: 231.38**	3.02E-07	4.79E-08	1.51E-06

[14]

[14] Trial 1 = risk assessment estimate using average values computed from BEACHES data.
Trial 2 = risk assessment estimate using full dataset for body weight and averages for all other variables.
Trial 3 = risk assessment estimate using full dataset for skin surface area and averages for all other variables.
Trial 4 = risk assessment estimate using full dataset for frequency of exposure and averages for all other variables.
Trial 5 = risk assessment estimate using full dataset for chemical concentration and averages for all other variables.
Trial 6 = risk assessment estimate using full dataset for body weight, skin surface area, frequency of exposure, and chemical concentration.

Table 11b. Non-cancer risk estimates for chrysene based on varying datasets.

	Inputs				Simulation Output		
Trial	**Body Weight (kg)**	**Skin Surface Area (cm2)**	**Frequency (days/yr)**	**Concentration (mg/kg)**	**Mean**	**Value (2.5%)**	**Value (97.5%)**
1	34.8	12582	3	49.71	3.45E-06	NA	NA
2	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	12582	3	49.71	2.75E-06	1.74E-06	4.68E-06
3	34.8	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	3	49.71	3.63E-06	2.51E-06	5.25E-06
4	34.8	12582	**Min: 1 Likeliest: 3 Max: 50**	49.71	1.74E-05	4.27E-06	4.57E-05
5	34.8	12582	3	**Min: 0.011175 Likeliest: 49.71 Max: 231.38**	5.62E-06	1.74E-06	1.29E-05
6	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	**Min: 1 Likeliest: 3 Max: 50**	**Min: 0.011175 Likeliest: 49.71 Max: 231.38**	2.34E-05	3.72E-06	1.17E-04

[15]

[15] Trial 1 = risk assessment estimate using average values computed from BEACHES data.
Trial 2 = risk assessment estimate using full dataset for body weight and averages for all other variables.
Trial 3 = risk assessment estimate using full dataset for skin surface area and averages for all other variables.
Trial 4 = risk assessment estimate using full dataset for frequency of exposure and averages for all other variables.
Trial 5 = risk assessment estimate using full dataset for chemical concentration and averages for all other variables.
Trial 6 = risk assessment estimate using full dataset for body weight, skin surface area, frequency of exposure, and chemical concentration.

Table 12a. Cancer risk estimates for fluoranthene based on varying datasets.

	Inputs				Simulation Output		
Trial	**Body Weight (kg)**	**Skin Surface Area (cm2)**	**Frequency (days/yr)**	**Concentration (mg/kg)**	**Mean**	**Value (2.5%)**	**Value (97.5%)**
1	34.8	12582	3	9.35	1.48E-08	NA	NA
2	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	12582	3	9.35	1.20E-08	7.94E-09	1.86E-08
3	34.8	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	3	9.35	1.55E-08	1.17E-08	2.00E-08
4	34.8	12582	**Min: 1 Likeliest: 3 Max: 50**	9.35	7.76E-08	2.29E-08	1.74E-07
5	34.8	12582	3	**Min: 0.007483 Likeliest: 4.635 Max: 61.00**	3.09E-08	8.51E-09	7.24E-08
6	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	**Min: 1 Likeliest: 3 Max: 50**	**Min: 0.007483 Likeliest: 4.635 Max: 61.00**	1.32E-07	2.14E-08	5.75E-07

[16]

[16] Trial 1 = risk assessment estimate using average values computed from BEACHES data.
Trial 2 = risk assessment estimate using full dataset for body weight and averages for all other variables.
Trial 3 = risk assessment estimate using full dataset for skin surface area and averages for all other variables.
Trial 4 = risk assessment estimate using full dataset for frequency of exposure and averages for all other variables.
Trial 5 = risk assessment estimate using full dataset for chemical concentration and averages for all other variables.
Trial 6 = risk assessment estimate using full dataset for body weight, skin surface area, frequency of exposure, and chemical concentration.

Table 12b. Non-cancer risk estimates for fluoranthene based on varying datasets.

	Inputs				Simulation Output		
Trial	**Body Weight (kg)**	**Skin Surface Area (cm2)**	**Frequency (days/yr)**	**Concentration (mg/kg)**	**Mean**	**Value (2.5%)**	**Value (97.5%)**
1	34.8	12582	3	9.35	1.15E-06	NA	NA
2	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	12582	3	9.35	9.33E-07	6.17E-07	1.45E-06
3	34.8	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	3	9.35	1.23E-06	9.12E-07	1.58E-06
4	34.8	12582	**Min: 1 Likeliest: 3 Max: 50**	9.35	6.17E-06	1.78E-06	1.38E-05
5	34.8	12582	3	**Min: 0.007483 Likeliest: 4.635 Max: 61.00**	2.45E-06	6.61E-07	5.75E-06
6	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	**Min: 1 Likeliest: 3 Max: 50**	**Min: 0.007483 Likeliest: 4.635 Max: 61.00**	1.02E-05	1.66E-06	4.47E-05

[17]

[17] Trial 1 = risk assessment estimate using average values computed from BEACHES data.
Trial 2 = risk assessment estimate using full dataset for body weight and averages for all other variables.
Trial 3 = risk assessment estimate using full dataset for skin surface area and averages for all other variables.
Trial 4 = risk assessment estimate using full dataset for frequency of exposure and averages for all other variables.
Trial 5 = risk assessment estimate using full dataset for chemical concentration and averages for all other variables.
Trial 6 = risk assessment estimate using full dataset for body weight, skin surface area, frequency of exposure, and chemical concentration.

Table 13a. Cancer risk estimates for phenanthrene based on varying datasets.

	Inputs				Simulation Output		
Trial	**Body Weight (kg)**	**Skin Surface Area (cm2)**	**Frequency (days/yr)**	**Concentration (mg/kg)**	**Mean**	**Value (2.5%)**	**Value (97.5%)**
1	34.8	12582	3	254.70	3.02E-07	NA	NA
2	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	12582	3	254.70	2.45E-07	1.62E-07	3.89E-07
3	34.8	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	3	254.70	3.16E-07	6.03E-07	4.17E-07
4	34.8	12582	**Min: 1 Likeliest: 3 Max: 50**	254.70	1.66E-06	4.79E-07	3.72E-06
5	34.8	12582	3	**Min: 0.007111 Likeliest: 322.46 Max: 725.90**	3.98E-07	1.62E-07	6.76E-07
6	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	**Min: 1 Likeliest: 3 Max: 50**	**Min: 0.007111 Likeliest: 322.46 Max: 725.90**	1.78E-06	4.17E-07	6.03E-06

[18]

[18] Trial 1 = risk assessment estimate using average values computed from BEACHES data.
Trial 2 = risk assessment estimate using full dataset for body weight and averages for all other variables.
Trial 3 = risk assessment estimate using full dataset for skin surface area and averages for all other variables.
Trial 4 = risk assessment estimate using full dataset for frequency of exposure and averages for all other variables.
Trial 5 = risk assessment estimate using full dataset for chemical concentration and averages for all other variables.
Trial 6 = risk assessment estimate using full dataset for body weight, skin surface area, frequency of exposure, and chemical concentration.

Table 13b. Non-cancer risk estimates for phenanthrene based on varying datasets.

	Inputs				Simulation Output		
Trial	**Body Weight (kg)**	**Skin Surface Area (cm2)**	**Frequency (days/yr)**	**Concentration (mg/kg)**	**Mean**	**Value (2.5%)**	**Value (97.5%)**
1	34.8	12582	3	254.70	2.36E-05	NA	NA
2	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	12582	3	254.70	1.91E-05	1.26E-06	3.02E-05
3	34.8	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	3	254.70	2.45E-05	1.86E-05	3.24E-05
4	34.8	12582	**Min: 1 Likeliest: 3 Max: 50**	254.70	1.29E-04	3.80E-05	2.95E-04
5	34.8	12582	3	**Min: 0.007111 Likeliest: 322.46 Max: 725.90**	3.09E-05	1.26E-05	3.31E-05
6	**Min: 19.2 Likeliest: 34.8 Max: 82.4**	**Min: 7430.253 Likeliest: 12582.02 Max: 21258.03**	**Min: 1 Likeliest: 3 Max: 50**	**Min: 0.007111 Likeliest: 322.46 Max: 725.90**	1.38E-04	3.24E-05	4.68E-04

[19]

[19] Trial 1 = risk assessment estimate using average values computed from BEACHES data.
Trial 2 = risk assessment estimate using full dataset for body weight and averages for all other variables.
Trial 3 = risk assessment estimate using full dataset for skin surface area and averages for all other variables.
Trial 4 = risk assessment estimate using full dataset for frequency of exposure and averages for all other variables.
Trial 5 = risk assessment estimate using full dataset for chemical concentration and averages for all other variables.
Trial 6 = risk assessment estimate using full dataset for body weight, skin surface area, frequency of exposure, and chemical concentration.

Table 14. Assumption values used in risk estimate simulations in Crystal Ball.[66]

	ASSUMPTIONS			
	Distribution	**Minimum**	**Likeliest (Median)**	**Maximum**
EXPOSURE DATA				
Body Weight (kg)	Triangular	19.2	34.8	82.4
Skin Surface Area(CM^2)	Triangular	7430.253	12582.02	21258.03
Frequency of Exposure (days/yr)	Triangular	1	3	50
CHEMICAL DATA				
Benzo[b]fluoranthene (mg/kg)	Triangular	0.007211	6.07	23.36
Benzo[e]pyrene (mg/kg)	Triangular	0.0038	12.12	13.05
C3-Naphthalene (mg/kg)	Triangular	0.01094	1616.11	18.58.97
Chrysene (mg/kg)	Triangular	0.011175	49.71	231.38
Fluoranthene (mg/kg)	Triangular	0.007483	4.635	61.00
Phenanthrene (mg/kg)	Triangular	0.007111	322.46	725.90

20

[20] Minimum, likeliest, and maximum values for body weight, frequency of exposure, and skin surface area were obtained from BEACHES data. Median values were used as likeliest value to create distribution. Minimum, likeliest, and maximum values for chemical concentrations were obtained from combining data from EPA sampling and fate and transport modeling within the BEACHES study.

Table 15a. Mean cancer risk estimate values for six chemicals from oral, dermal and inhalation exposure routes.

Chemical	Oral	Dermal	Inhalation	Total
	Cancer Risk *(mean)*	Cancer Risk *(mean)*	Cancer Risk *(mean)*	
Benzo[b]fluoranthene	2.63E-07	2.82E-06	5.13E-18	
Benzo[e]pyrene	2.51E-06	2.45E-05	5.13E-17	
C3-Naphthalene	9.12E-07	2.00E-07	4.27E-17	
Chrysene	2.45E-08	2.63E-07	5.50E-19	
Fluoranthene	3.16E-08	6.92E-08	7.08E-19	
Phenanthrene	3.89E-07	9.77E-07	1.02E-17	
Total	**4.13E-06**	**2.88E-05**	**1.11E-16**	**3.30E-05**

[21]

[21] Data generated from Crystal Ball.[66]

Table 15b. Mean non-cancer risk estimate values for six chemicals from oral, dermal and inhalation exposure routes.

Chemical	Oral	Dermal	Inhalation	Total
	Non-Cancer Risk *(mean)*	Non-Cancer Risk *(mean)*	Non-Cancer Risk *(mean)*	
Benzo[b]fluoranthene	2.04E-05	2.19E-04	3.98E-16	
Benzo[e]pyrene	1.95E-04	1.91E-03	3.98E-15	
C3-Naphthalene	7.08E-05	1.55E-05	3.31E-15	
Chrysene	1.91E-06	2.09E-05	4.27E-17	
Fluoranthene	2.45E-06	5.37E-06	5.62E-17	
Phenanthrene	3.09E-05	7.59E-05	7.94E-16	
Total	**3.21E-04**	**2.25E-03**	**8.58E-15**	**2.57E-03**

[22]

[22] Data generated from Crystal Ball.[66]

Table 16: Input values for chemical risk assessment of twelve chemicals missing data for tar.

	Concentration (mg/kg)			Slope Factor				
Chemicals	**Sediment**	**Weathered Oil**	**Tar**	**Oral**	**Dermal**	**Inhalation**	**RBA Oral**	**ABS Dermal**
Acenaphthene	0.01637	0.1638	NA	0.06	0.03	0.03	0.5	0.01
Acenaphthylene	0.008792	0.0145	NA	0.03	0.03	0.03	0.5	0.01
Anthracene	0.01404	10.15	NA	0.30	0.15	0.15	0.5	0.01
Benz[a]anthracene	0.08517	13.26	NA	0.73	1.46	0.31	0.5	0.01
Benzo[a]pyrene	0.02968	0.0888	NA	0.073	0.146	0.031	0.5	0.01
Benzo[g,h,i]perylene	0.03759	0.521	NA	0.03	0.015	0.015	0.5	0.01
Benzo[k]fluoranthene	0.06724	4.586	NA	7.3	14.6	3.1	0.5	0.01
Dibenz[a,h]anthracene	0.02398	0.133	NA	7.3	14.6	3.1	0.5	0.01
Fluorene	0.03472	6.461	NA	0.04	0.02	0.02	0.5	0.01
Indeno[1,2,3-cd]pyrene	0.03214	0.345	NA	0.73	1.46	0.31	0.5	0.01
Naphthalene	0.01367	0.0336	NA	0.02	8.57×10^{-4}	0.02	0.5	0.01
Pyrene	0.05729	9.59	NA	0.03	0.015	0.015	0.5	0.01

[23]

[23] Chemical concentration data were obtained from fate and transport modeling within the BEACHES study. Oral, dermal, and inhalation slope factor values, oral RBA, and dermal RBS were obtained from Center for Environmental Toxicology report (2005). [61]
NA = not available
RBA = relative bioavailability
ABS = absorption factor

Table 17. Assumption values used in risk estimate simulations in Crystal Ball.[66]

	ASSUMPTIONS			
	Distribution	**Minimum**	**Likeliest (Median)**	**Maximum**
EXPOSURE DATA				
Body Weight (kg)	Triangular	19.2	34.8	82.4
Skin Surface Area (cm^2)	Triangular	7430.253	12582.02	21258.03
Frequency of Exposure (days/year)	Triangular	1	3	50

[24]

[24] Minimum, likeliest, and maximum values for body weight, frequency of exposure, and skin surface area were obtained from BEACHES data. Median values were used as likeliest value to create distribution.

Table 18a. Mean cancer risk estimate values for twelve chemicals from oral, dermal and inhalation exposure routes using concentration from sediment and weathered oil. Data generated from Crystal Ball.[66]

	Cancer Risk							
Chemical	**Oral Risk *(mean)***		**Dermal Risk *(mean)***		**Inhalation Risk *(mean)***		**Total**	
	Sediment	Weathered Oil	Sediment	Weathered Oil	Sediment	Weathered Oil		
Acenaphthene	4.37E-11	4.27E-10	1.10E-10	1.15E-09	1.02E-21	1.05E-20		
Acenaphthylene	1.20E-11	1.95E-11	6.31E-11	1.00E-10	5.50E-22	8.91E-22		
Anthracene	1.86E-10	1.32E-07	4.68E-10	3.31E-07	4.37E-21	3.24E-18		
Benz[a]anthracene	2.75E-09	4.37E-07	2.69E-08	4.07E-06	5.62E-20	8.51E-18		
Benzo[a]pyrene	2.19E-08	1.51E-06	2.14E-07	1.48E-05	4.37E-19	2.88E-17		
Benzo[g,h,i]perylene	5.13E-11	7.24E-10	1.23E-10	1.74E-09	1.20E-21	1.66E-20		
Benzo[k]fluoranthene	1.00E-10	2.88E-10	9.12E-10	2.95E-09	2.04E-21	5.75E-21		
Dibenz[a,h]anthracene	8.32E-09	4.57E-08	7.76E-08	4.17E-07	1.55E-19	8.51E-19		
Fluorene	6.17E-11	1.15E-08	1.55E-10	2.95E-08	1.51E-21	2.69E-19		
Indeno[1,2,3-cd]pyrene	1.07E-09	1.17E-08	1.05E-08	1.10E-07	2.09E-20	2.19E-19		
Naphthalene	1.20E-11	2.95E-11	2.57E-12	6.17E-12	5.89E-22	1.41E-21		
Pyrene	7.76E-11	1.29E-08	2.04E-10	3.02E-08	1.78E-21	3.09E-19		
Total	**3.46E-08**	**2.17E-06**	**3.31E-07**	**1.98E-05**	**6.82E-19**	**4.23E-17**	**Sediment**	**Weathered Oil**
							3.65E-07	**2.20E-05**
Total	**2.20E-06**		**2.01E-05**		**4.30E-17**		**2.23E-05**	

Table 18b. Mean non-cancer risk estimate values for twelve chemicals from oral, dermal and inhalation exposure routes using concentration from sediment and weathered oil. Data generated from Crystal Ball.[66]

	Non-Cancer Risk							
Chemical	**Oral Risk *(mean)***		**Dermal Risk *(mean)***		**Inhalation Risk *(mean)***		**Total**	
	Sediment	Weathered Oil	Sediment	Weathered Oil	Sediment	Weathered Oil		
Acenaphthene	3.47E-09	3.31E-08	8.51E-09	8.91E-08	7.94E-20	8.13E-19		
Acenaphthylene	9.33E-10	1.51E-09	4.90E-09	7.76E-09	4.27E-20	6.92E-20		
Anthracene	1.45E-08	1.05E-05	3.72E-08	2.57E-05	3.39E-19	2.51E-16		
Benz[a]anthracene	2.14E-07	3.39E-05	2.14E-06	3.16E-04	4.37E-18	6.61E-16		
Benzo[a]pyrene	1.70E-06	1.17E-04	1.66E-05	1.17E-03	3.39E-17	2.29E-15		
Benzo[g,h,i]perylene	3.98E-09	5.62E-08	9.55E-09	1.35E-07	9.55E-20	1.29E-18		
Benzo[k]fluoranthene	7.76E-09	2.24E-08	7.08E-08	2.29E-07	1.58E-19	4.57E-19		
Dibenz[a,h]anthracene	6.46E-07	3.55E-06	3.02E-06	3.24E-05	1.20E-17	6.61E-17		
Fluorene	4.79E-09	8.91E-07	1.20E-08	2.29E-06	1.17E-19	2.09E-17		
Indeno[1,2,3-cd]pyrene	8.32E-08	9.12E-07	8.13E-07	8.51E-06	1.32E-18	1.70E-17		
Naphthalene	9.33E-10	2.34E-09	2.00E-10	4.79E-10	4.57E-20	1.12E-19		
Pyrene	6.03E-09	1.00E-06	1.58E-08	2.40E-06	1.38E-19	2.40E-17		
Total	**2.68E-06**	**1.68E-04**	**2.27E-05**	**1.56E-03**	**5.26E-17**	**3.33E-15**	**Sediment**	**Weathered Oil**
							2.54E-05	**1.73E-03**
Total	**1.71E-04**		**1.59E-03**		**3.39E-15**		**1.76E-03**	

Discussion

Examining children's health risks from environmental exposures is a complex process. The interaction between a child and his or her environment, coupled with child-specific behaviors, such as higher rate of hand-to-mouth actions, higher rate of non-dietary ingestion, crawling and prolonged time spent near the ground, and increased physical activity, creates an exposure profile that is distinctly different than for adults. In some scenarios, children can experience increased exposures compared to adults for the same environmental context. This exposure profile can also change based on sociological and psychological factors. The unique exposure profile for children can result in adverse health outcomes even in scenarios where adults are not considered at risk. For example, children are at greater risk from exposure to chemical hazards found in soil or sand (such as at beach sites), due to young children spending a majority of time closer to the ground, and potentially crawling in and/or eating the contaminated soil.[63] It is important to evaluate factors used in human health risk assessment for how they might represent exposures experienced by a child.

A sensitivity analysis was conducted to determine which variables might drive overall risk estimates. First, a baseline risk estimate was computed using average values for each variable. Then, one dataset was inputted into a Crystal Ball simulation, while averages were used for all remaining variables. A triangular distribution was chosen for each dataset, since minimum and maximum values were known. In the last simulation, datasets were used for all four variables. The only single trial where an increase from the baseline was seen in most cases was for frequency of exposure. Comparing the three datasets generated from the BEACHES study demographic and survey information, the greatest range in values is seen

for frequency of exposure (1 to 50 days). Ranges for body weight (19.2 to 82.4kg) and skin surface area (7,430 21,258 cm^2) are not as great compared to frequency of exposure. A greater range in values may have contributed to the increases in aggregate risk estimates for these chemicals. Furthermore, skin surface area is only used in risk estimates for dermal exposure, so it did not have a substantial impact on overall aggregate risk estimates.

In the context of beach-related behavior, families who might report 50 days per year visiting the beach are likely to be those that live close to beach sites. Increase in risk estimate values from varying frequency of exposure in this sensitivity analysis could suggest that frequency of visiting the beach environment is a driver of exposure; residents who live close to beaches and visit them regularly, such as those living on Galveston Island, may experience higher rates of exposure to OSCs and subsequent adverse health outcomes compared to those visiting the beach sporadically from other cities. Increase can occur in time spent at beaches and number of visits per year.

A Monte Carlo analysis was conducted using chemical information from a fate and transport modeling sub-project within the BEACHES study, combined with existing concentration information from EPA sampling immediately following the DWH oil spill. Six chemicals were selected from a larger dataset due to existing shoreline chemical concentration information for sediment, weathered oil, and tar. Following the DWH oil spill, approximately 22% of oil that was released deposited onto shoreline sediment or was carried to shorelines as tar.[68] Weathered oil is used in this human health risk assessment to represent the upper limit of OSC concentration that can exist in sediment following shoreline oiling.[61] Chemical-specific variables for slope factor, oral relative bioavailability factor, and

absorption factor were extracted from the Center for Environmental Toxicology Technical Report. .[65] For both cancer and non-cancer risk estimates of this set of six chemicals, the highest values were seen for benzo[e]pyrene. The mean risk estimates are highest in dermal exposure, followed closely by oral exposure; estimates were lowest in inhalation exposure. This suggests that the former two exposure routes should be of greatest concern when evaluating and communicating children's health risks in the beach environment.

A second Monte Carlo analysis was conducted using BEACHES datasets and chemical concentration data for twelve chemicals that had missing information for concentration in tar. Single values were used for chemical concentration, and health risk estimates were generated for exposures to concentration in sediment and weathered oil. For both cancer and non-cancer risk estimates of the second set of twelve chemicals, the highest values were seen for benzo[a]pyrene. Since weathered oil represents the upper limit of concentration, highest risk estimates were seen for weathered oil calculations compared to sediment. Each beach site may have a different distribution of chemicals in different zones; further analysis is necessary to determine how the composition of beach sites impact children's play behavior, and how that may translate in terms of exposure to different OSCs in the various beach locations.

The mean risk estimates are highest in dermal exposure, followed closely by oral exposure; estimates were lowest in inhalation exposure. These risk estimates are missing information for tar; as a result, cumulative risk might be higher than what is presented here. This suggests that communications regarding children's health risks to families following an oil spill event should focus on oral and dermal exposure scenarios. This translates to proper

hygiene practices during and following beach play – limiting ingestion or mouthing of objects that are covered in sand, and thoroughly cleaning sand and water from the child's skin. In analyses of the first six chemicals, as well as in the latter twelve chemicals, overall risk estimates were relatively low; however, this assessment only accounts for 18 OSCs; crude oil contains hundreds of compounds, and additional chemical by-products are created when crude oil comes into contact and reacts with water and air.[69]

OBJECTIVE 3: ANALYSIS OF POLICIES FOR RECREATIONAL BEACH USE AND CLOSURES

Local and National Regulations Governing Beach Advisories and Closures

Analysis of local procedures on beach closures in the event of contamination will be limited to the two locations included in the BEACHES study, Galveston County and Miami-Dade County, as well as relevant national protocols.

Galveston County Policy on Beach Closures

Following mandates from the federal BEACH Act, Texas has implemented a beach advisory system called Texas Beach Watch, administered and maintained by the Texas General Land Office with funding and support from the EPA. Texas Beach Watch monitors water quality through the use of fecal indicator bacteria *(Enterococci)* at 167 stations located on 65 different beach sites in various counties, including Galveston County. Within Galveston County, there are 52 water quality monitoring stations. During peak beach use season, running between May and September, and in March, during Spring Break period, water samples are collected weekly at each station. During off-peak months, water samples are collected at two-week intervals.[70] Water quality monitoring data is uploaded to Texas Beach Watch Information system, and later archived with BEACON.

If concentrations of fecal indicator bacteria exceed EPA limits in a collected water sample, an advisory is issued for the corresponding beach site. Water samples are collected at the affected site every 24 hours until the concentration falls below exceedance limit. Although an advisory is issued for the beach location both online and through physical signage at the affected beach in both English and Spanish, the beach itself is not closed to the

public unless concentrations remain above allowable limits for more than 48 hours. People visiting the beach make the decision to move to another beach site or remain at affected location.[71] The signage at the beach indicates a warning of potential illness from beach use (Figure 5) and the online advisory states only that fecal indicator bacteria levels exceeded EPA standard at a given location.[70] Specific health information regarding beach use in affected areas can be found on the Galveston County Health District page on Beach Water Advisories, where it identifies those with open cuts and sores, immune-suppressive conditions, diabetes, liver disease, or cancer are at increased risk of infection. The site also recommends immediate attention, and if needed, medical attention in the event of experiencing an open cut or wound while at the beach.[71]

The Texas Commission on Environmental Quality (TCEQ) also monitors surface waters throughout the state; routine monitoring every six months is conducted at over 3,200 stations across the state and continuous, real-time monitoring occurs at 35 select watersheds. Routine monitoring efforts collect sampling data on water flow, nutrients (phosphorus, nitrogen, etc.), bacterial indicators, and other ambient field measurements, such as temperature and pH. At certain sites, data on aquatic life and chemical concentration in sediment and water is also collected; chemicals identified to be of concern are those that have demonstrated toxicity in aquatic organisms.[72] However, in the most recent report on water quality monitoring data, the TCEQ did not collect and chemical-specific samples at recreational beach sites.[73]

Miami-Dade County Policy on Beach Closures

Following implementation of the BEACH Act, the state of Florida instituted the Florida Healthy Beaches Program, which collects water samples from 32 regions along the shoreline for both the GOM-facing and Atlantic Ocean-facing coasts. Samples are collected and analyzed for fecal indicator bacteria (*Enterococci*) every two weeks from March to October, coinciding with beach use activity for most of the state. If the concentration of fecal indicator bacteria exceeds an established upper limit in both an initial and subsequent water sample, a beach advisory is issued for the beach sampling site. Similar to protocols in Texas, Florida issues an advisory to inform beachgoers, but does not close the beach site in the event of fecal indicator bacteria exceedances. The Florida Healthy Beaches Program also partners with Florida Fish and Wildlife Conservation and the Florida Department of Health to monitor harmful algal blooms and other aquatic toxins and pathogens.[74]

The Florida Department of Environmental Protection is the state equivalent to the TCEQ, and monitors watersheds across the state for various physical, biological and chemical indicators. However, water samples are limited to lakes, streams, rivers, canals, and aquifers. There is no established routine monitoring of chemical contaminants in beach zones.[75]

National Sampling Protocols to Inform State Agencies

Nationwide sampling of coastal waters to evaluate potential hazards for human health and ecosystems occurs approximately every five years by the EPA; the program, called the National Coastal Condition Assessment (NCCA) collects data on four indicators – biological (measure of ecosystem health), chemical (including contaminants in sediment), physical, and

human health (recreational potential, commercial fish tissue contaminants) for coastal waters extending from the shoreline to the nearshore boundary of the open water for both oceans and the Great Lakes. NCCAs are conducted every five years; the latest NCCA report was issued in 2010, and the most recent sampling cycle was conducted in 2015. An updated report and new sampling cycle is scheduled to be generated in 2020. The NCCA serves as a general monitoring tool for coastal water quality, and has not been used to inform beach closures.[76]

Coastline sampling for chemical contamination has occurred in emergency situations, such as immediately following DWH oil spill. EPA collected data on water, sediment, air, and waste between April and October 2010. Human health benchmarks were used to assess cancer and non-cancer risk from exposure to metals, VOCs, SVOCs, and PAHs. The human health benchmark used in this assessment was 90 hours of exposure from skin contact and accidental ingestion of water by a child swimmer. Sampling and subsequent risk data was provided to local agencies for all states affected by DWH oil spill, and each state and region made individual decisions regarding recreational beach closures.[77]

Strengths and Limitations of Regulations Governing Beach Advisories

Following the DWH oil spill, EPA conducted emergency sampling of coastlines in Florida, Alabama. Mississippi, Louisiana, and Texas to evaluate the potential health risks to humans and ecosystems along the GOM. In the data analysis for human health risks, benchmarks were used for children to determine whether a cancer or non-cancer health risk existed (yes or no). Using child benchmarks constitutes a conservative approach that takes

into consideration a vulnerable population (children) and ensures the reported risks reflect all populations that may be using the beach.[78]

Advisories and closures of recreational beach sites are largely governed by available data on various water quality factors. EPA sampling activities might inform state agencies regarding potential beach closures, and states and territories are required to report beach closures to the EPA, but generally are the primary decision-makers to close or reopen a beach.[76] Based on current, existing information on procedures regulating beach advisories and closures, in most cases advisories are issued for biological contamination, with closures being rare. Advisories associated with chemical contamination appear uncommon except in cases of major events, such as DWH oil spill. Both biological and chemical-associated beach advisory and closure recommendations are limited by available water sampling data, which is collected by states under mandate by the BEACH Act and using funding from EPA. However, these mandates only compel water quality analysis for biological pathogens; in the case of Florida and Texas, there is no routine sampling of water for chemical contaminant analysis at recreational beach sites. Furthermore, EPA funding is sensitive to national budgetary initiatives; for the past 3 years, EPA funding for BEACH Act-related activities have declined.[79]

Recommendations for Regulations Governing Beach Advisories

State and local agencies rely on quantitative data on water quality in order to manage public beach use. Many local agencies must weigh their obligation to inform the public regarding beach advisories and promoting recreational beach use as a revenue-generating instrument. A 2004 study conducted by Turbow et al. found a 40% reduction in recreational

beach use at selected California beaches following a closure due to bacterial pollution.[80] Currently, the only routine monitoring of chemical contaminants in beach environments is conducted in an emergency following a spill or other disaster event. Even in these cases, it is difficult to interpret sampling data without a baseline measurement prior to the disaster event.[81] Following DWH oil spill, many beaches and commercial fisheries were closed as a preventative measure rather than a response to available exposure data.[82] In order for local and state agencies to make logical decisions regarding beach advisories and closures for the protection of human health, routine water sampling programs should be established to gather data on potential chemical hazards. Current environmental policies should be broadened to include sampling requirements outside damage assessment situations; consistent sampling for chemical hazards would not only help inform local agencies tasked with protecting public health, but would also provide a baseline measurement of chemical constituents in the environment in the event of another disaster, and may potentially limit the impact of lost revenue.[81]

The biggest limitation to implementing chemical hazard monitoring is the vast profile of potential chemicals in the water environment; oil alone has hundreds of chemical constituents and byproducts. In Texas, there is limited testing of water for chemicals, but this testing is primarily for sediment in inland watersheds. The cost of sampling for every possible OSC would likely exceed current and future funding allocation. At the federal level, the EPA should consider raising the budget assisting states in their water sampling programs. This would allow states to implement sampling programs for chemicals to run alongside existing sampling programs for bacterial indicators. In the event that budget constraints

remain, state programs can utilize data generated from many studies following the DWH oil spill studying the primary residual compounds following oil contamination of nearshore environments;[83] additionally, technologies have advanced to create chemical indicators, similar to fecal indicator bacteria, to detect OSCs in water samples.[84] These two methods – utilizing indicators and novel technologies - would limit the scope of chemical testing, thereby mitigating the burden of funding constraints. Acceptable thresholds can be established using current information on chemical toxicity, as well as risk assessment models for various populations, including children.

Preliminary indications from this risk assessment process suggest that frequency of exposure, specifically number of days per year a population interacts with the beach environment, drives risk estimates. Populations visiting the beach regularly, especially those that live near the beach, such as in the case for many residents of Galveston and Miami-Dade counties, may be at higher risk for exposure to OSCs. It will be important for decision-makers to take this into consideration when determining whether to post an advisory or close an affected beach site, and the manner in which they communicate one or the other. Special health warnings may need to be issued for local communities who use public beaches at a higher rate compared to tourists; a possible recommendation would be to provide a health advisory to families who visit the beach more than twice a week during the peak seasons. These specialized advisories could provide additional information regarding the health risks of chronic exposure to beaches contaminated by OSCs. Similar to existing policies encompassing bacterial contamination, chemical-exposure advisories can be posted at sites and online, deliver information in plain language, and allow the public to make their own

decisions regarding their exposure to the beach environment. Additionally, as in the case with bacterial contamination, any advisories related to chemical contamination need to be informed by sampling data in order to prevent the possibility of inciting unnecessary fear or avoidance of beaches. These advisories cannot be presented without the support of consistent scientific data. Based on survey data collected from the BEACHES study, preferences for receiving warnings regarding beach advisories, closures, and other public announcements appear to vary by race; white families tend to prefer information via social media and other phone-based services, while black families prefer TV and radio announcements, site postings, newspapers, and word of mouth.[85] Communication of beach advisories and closures from oil-spill related events should consider varied routes in order to ensure consistent and inclusive dissemination of information.

Protocols and regulations for the management of public beach use has not caught up to the vast array of potential chemical hazards that can exist in the beach environment. The lack of available data regarding exposures at beach sites is a significant limitation to informing state and local agencies, as well as informing the public. State and national lawmakers have the opportunity to develop new and needed water sampling and reporting programs by leveraging ten years of research regarding the characteristics, transport of, and impact of OSCs in the marine environment. These programs will be especially important in the event of a future marine oil spill or hazardous chemical release. Special considerations for health communication need to be made for families who have higher-than-average exposure to chemical contaminants through recreational use of beaches, and messaging should specifically include recommendations for hygiene practices on and off the beach in

order to mitigate health risks from oral and dermal exposure routes. Finally, any future assessments of potential risk need to account for exposures by children and other vulnerable populations.

Figure 5: Physical signage for beach advisory in Texas. Photo courtesy of Texas Beach Watch.[70]

FINAL DISCUSSION AND CONCLUSION

The DWH oil spill signified the largest oil spill in U.S. history, discharging over 200 million gallons of crude oil and gaseous hydrocarbons into the GOM and shorelines along Florida, Alabama, Mississippi, Louisiana and Texas.[5] Since the 2010 disaster, there has been considerable research focused on the impact of the spill on ecosystems, economy, and the mental, physical, and social health of affected populations.[17] In regards to human health outcomes, a majority of focus has been given to the health of first responders[11] and adults living and working in affected areas in the GOM.[18]

Children's' age-specific behaviors, such as mouthing, crawling, increased physical activity, lack of consistent hygiene practices, and indiscriminate ingestion of substances, puts them at greater risk of exposure to environmental contaminants[86] . Some studies have investigated the relationship between child behavior patterns and the outdoor environment,[87] but few studies have investigated the potential health risks to children playing at beach sites that may have been contaminated by OSCs. Children participating in the BEACHES study ranged from 10 to 83 months of age. In the context of the beach environment, children in this age range experience heightened exposures via oral, dermal, and inhalation routes. They are likely to spend more time outdoors, such as at beaches, where they may come into contact with various hazards not found at home. Additionally, they tend to participate in increased and more vigorous play activities and likely have prolonged contact with contaminated sand and water, which might not be washed away properly if effective hygiene practices are not present. Hand-to-mouth activity is high in very young children and does not begin to subside

until closer to 60 months of age.[86] These behaviors can lead to higher exposure to OSCs that may be found at beach sites following an oil spill.

A key objective of this project, funded by GoMRI, was to conduct a human health risk assessment using exposure variables generated from the BEACHES field study and determine which factors drive overall risk estimates. A risk assessment was conducted for three different sets of chemicals: the first set was consistent with a prior risk assessment conducted by Black et al. (2016), and the second set utilized concentrations generated from fate and transport modeling of OSCs in sediment, weathered oil, and tar. The third set of chemicals also came from the fate and modeling project within BEACHES, but included concentrations for sediment and weathered oil only. In all three risk assessments, overall estimates were highest in dermal exposure routes and lowest in inhalation exposure routes. In context, children playing at beach sites may experience higher risk from prolonged skin contact with contaminated sand and water, and risk of exposure from the inhalation pathway might not be of greatest concern.

The micro-activity data generated from video-translation of children's beach play represents a significant output from the BEACHES study but has not been incorporated into this analysis. This micro-activity information can give more insight into specific behavioral inputs, such as soil intake rate and inhalation rate, as well as dermal contact patterns, such as loading, reloading, and reloading of sand and water onto the skin through different play behaviors, on a per hour basis. Video-translation data can also demonstrate where children spend most of their time when they visit the beach, and what surfaces, other than the sand and water, they may come in contact with (toys, other children or animals, etc.). This narrow

timeframe of highly specific behavior and exposure data can subsequently be extrapolated to predict a child's exposure patterns over the course of a day, or a year, or a set of years.[10]

For these risk analyses, certain assumptions were made. First, it was assumed that children playing in the beach environment would be exposed to the same concentrations of OSCs equally in all locations of the beach environment. In reality, the distribution of OSCs will differ in different beach zones (sand, water, intertidal zone, etc.). Some chemicals might be in higher concentrations in one location, rather than equally dispersed across the beach. Additionally, it was assumed for this risk assessment process that children would be exposed to the same chemical concentrations via the oral, dermal, and inhalation routes. Practically, children might experience higher exposure to some chemicals via the dermal or inhalation route, or experience little-to-no exposure via certain pathways. The use of mathematical weighting of chemical concentration values within specific exposure pathways has been explored as a possible method to address unequal distribution of OSCs in the environment and unequal exposures. Weighting has been previously utilized to assess the individual impacts of different chemicals within a mixture on the risk of non-Hodgkin lymphoma.[88] Lastly, it was assumed that all chemicals considered in these analyses not only have a cancer outcome (i.e, are carcinogenic), but also have the same cancer outcome. Studies in animal models evaluating specific cancer outcomes for OSCs are limited, so it is difficult to accurately predict whether every chemical constituent and byproduct found in crude oil will result in carcinogenic outcomes in humans.

Results from the sensitivity analysis suggests that frequency of exposure – days per year that families visited the beach – could be a driver of risk. This might be of greatest

concern for families that live near recreational beach sites, such as those living on Galveston Island or Key Biscayne, two locations of the BEACHES study. Families in close proximity to the beach environment may use the beach as their primary place for family recreation, and could potentially visit the beach up to or over 50 times per year. Taking into consideration timing of a potential oil spill (off-peak vs. summertime), as well as severity of the spill itself, children living in these areas are at higher risk of exposure from OSCs compared to children who only visit the beach one or two times a year.

An analysis of policy governing beach advisories and closures for Galveston and Miami-Dade counties reveals that advisories and closures are primarily dictated by exceedances of fecal indicator bacteria and other biological toxins; there is no monitoring of chemical contamination at recreational beach sites in both counties. Routine monitoring of chemical contaminants in Texas and Florida is sporadic, and is generally only conducted to determine ecosystem health for high-risk watersheds. Following the DWH oil spill, the EPA conducted sampling of sediment, weathered oil, and tar along affected coastlines and computed risk estimates addressing children as the population of focus to represent a conservative risk estimate. These estimates provided by the EPA were based on the risk scenario where children swimming might come into contact with contaminated water via oral and dermal exposure pathways. The EPA reported their findings to states, who were the final decision-makers regarding whether to close beach sites for public use. These risk estimates did not take into consideration potential exposure from contaminated sand. Since states and counties make the ultimate determination to close beach sites, it is important to communicate risk information that takes into consideration the types and magnitude of exposures affecting

children. Agencies should produce messaging that can be delivered through various channels (TV, radio, print, social media) and should specifically include recommendations for hygiene practices on and off the beach in order to mitigate health risks from oral and dermal exposure routes.

A significant limitation to this study is the lack of available information regarding concentrations of OSCs and other chemicals in the beach environment. Without routine sampling, it is difficult to predict which OSCs reach and persist in shorelines following a spill, and how these OSCs are distributed across the different regions of the beach (sand dunes, intertidal zone, etc.). In this risk assessment, it was assumed that children would be exposed to these chemical concentrations via all three exposure pathways. However, some OSCs do not contribute to risk as significantly as others in all exposure pathways. Risk assessments can try to include every possible chemical contaminant, but routine sampling data would help narrow the scope to focus on chemicals of greatest concern while concurrently providing an informed risk estimate that takes into consideration tangible environmental concentrations. Fate and transport modeling has begun to address the lack of chemical data, but there are limitations to each model.

In conclusion, risk assessment practices can provide information that advises policy protecting public health during an environmental disaster event. Methods used for risk assessment can be modified to address child-specific behaviors and increased susceptibility to hazards. Exposure factors, such as days spent at the beach, higher rates of mouthing and crawling behaviors, and increased physical activity in young children playing in the beach environment can drive risk estimates; this should be considered when communicating risk to

local communities who use these environments regularly. Finally, risk assessments are limited by available data regarding the toxicity of OSCs, as well as concentrations and distributions of chemical hazards in the beach environment.

APPENDICES

Appendix A: List of acronyms used in this document.

BEACH - BEACHES ENVIRONMENTAL ASSESSMENT AND COASTAL HEALTH ACT

BEACHES – BEACH EXPOSURE AND CHILD HEALTH STUDY

BEACON - BEACH ADVISORY AND CLOSING ONLINE NOTIFICATION SYSTEM

BCE – BEACH CLOSURE EVENT

CERCLA - COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION, AND LIABILITY ACT

CWA – CLEAN WATER ACT

DWH – DEEPWATER HORIZON

EPA – ENVIRONMENTAL PROTECTION AGENCY

GOM – GULF OF MEXICO

GOMRI – GULF OF MEXICO RESEARCH INITIATIVE

MCA – MONTE CARLO ANALYSIS

NCCA – NATIONAL COASTAL CONDITION ASSESSMENT

NCP – NATIONAL CONTINGENCY PLAN

NOAA – NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

OSC – OIL SPILL CHEMICAL

OPA – OIL POLLUTION ACT

PAH – POLYCYCLIC AROMATIC HYDROCARBON

PRA – PROBABILISTIC RISK ASSESSMENT

QMRA – QUANTITATIVE MICROBIAL RISK ASSESSMENT

RA – RISK ASSESSMENT

RI/IS - REMEDIAL INVESTIGATION AND FEASIBILITY STUDY

SVOC – SEMI-VOLATILE ORGANIC COMPOUND

TCEQ – TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

USCG – UNITED STATES COAST GUARD

USGS – UNITED STATES GEOLOGICAL SURVEY

VOC – VOLATILE ORGANIC COMPOUND

Appendix B: UTSPH CPHS IRB approval letter.

UTHealth
The University of Texas
Health Science Center at Houston

Committee for the Protection of Human Subjects
6410 Fannin Street, Suite 1100
Houston, Texas 77030

REVISED LETTER

Dr. Kristina Mena
UT-H - SPH - El Paso Regional Campus

NOTICE OF APPROVAL TO BEGIN RESEARCH **June 18, 2018**

HSC-SPH-18-0396 - Beach Exposure And Child HEalth Study (BEACHES)

Number of Subjects Approved: Target: 500 **/Screen:** 550

PROVISIONS: This approval relates to the research to be conducted under the above referenced title and/or to any associated materials considered at this meeting, e.g. study documents, informed consent, etc.

ADDITIONAL PROVISO: The protocol approved by the University of Miami (lead site) was not reviewed by the UTHealth Committee for the Protection of Human Subjects (CPHS). The UTHealth CPHS approval for this study is only valid for the activities outlined in the reviewed protocol. The study team members may observe research activities at non-UTHealth sites, but may not participate.

APPROVED: At a Convened Meeting on 05/25/2018

EXPIRATION DATE: 04/30/2019

CHAIRPERSON: L. Maximilian Buja, MD

L. Maximilian Buja

Subject to any provisions noted above, you may now begin this research.

CHANGES: The principal investigator (PI) must receive approval from the CPHS before initiating any changes, including those required by the sponsor, which would affect human subjects, e.g. changes in methods or procedures, numbers or kinds of human subjects, or revisions to the informed consent document or procedures. The addition of co-investigators must also receive approval from the CPHS. ALL PROTOCOL REVISIONS MUST BE SUBMITTED TO THE SPONSOR OF THE RESEARCH.

INFORMED CONSENT DETERMINATION: Signed Informed Consent Required,
Signed Parental Consent/One Parent Signature

INFORMED CONSENT: Informed consent must be obtained by the PI or designee(s), using the format and procedures approved by the CPHS. The PI is responsible to instruct the designee in the methods approved by the CPHS for the consent process. The individual obtaining informed consent must also sign the consent document. Please note that only copies of the stamped approved informed consent form can be used when obtaining consent.

HEALTH INSURANCE PORTABILITY AND ACCOUNTABILITY ACT (HIPAA):
Exempt from HIPAA

UNANTICIPATED RISK OR HARM, OR ADVERSE DRUG REACTIONS: The PI will immediately inform the CPHS of any unanticipated problems involving risks to subjects or others, of any serious harm to subjects, and of any adverse drug reactions.

RECORDS: The PI will maintain adequate records, including signed consent documents if required, in a manner that ensures subject confidentiality.

Revision includes additional proviso statement.

Appendix C: Survey for Beach Exposures given to parents of child participants of BEACHES study. Spanish version also available at time of study.

Survey for Beach Exposures **Alphanumeric Code for Subject _____**

Name of Adult: _____ Age:_____ Sex:_____

Contact Address: _____City_____ State_____ Zip Code_____

Email address: _____@_____, Phone number (optional):_____

Beach Area _____Date:_____Time:_____

Participated in Videotaping Y/N, Participated in Sand Adhesion Y/N.

This survey is open only to adults who have taken children to the beach within the past year. **Are you an adult?** Y/N. **Have you taken a child or children to play on the beach within the past year?** Y/N

Disclosure Statement: Participation in this survey is voluntary. The specific information you provide will not be released with your name. We will disclose only the combined results from our planned 400 surveys. If you complete this survey, we will provide you with a $25 gift card as a token of appreciation for your time. At any time you can chose to not complete the survey.

DEMOGRAPHICS

Adult Interviewee:

Gender: M/F/Other

Are you of Hispanic (includes Spanish decent and Latino – at least 50%)?

a. No, not of Hispanic, Latino, or Spanish Origin
b. Yes, Cuban
c. Yes, Puerto Rican
d. Yes, Venezuelan
e. Yes, Colombian
f. Yes, Mexican, Mexican Am., Chicano,
g. Yes, another Hispanic, Latino, or Spanish origin – Print Origin _____

What is your race?

a. White
b. Black or African American
c. American Indian or Alaska Native
d. Asian Indian
e. Chinese
f. Filipino
g. Japanese
h. Korean
i. Vietnamese
j. Other Asian _____
k. Native Hawaiian
l. Guamanian or Chamorro
m. Samoan
n. Other Pacific Islander _____

Country of birth: USA or _____

What is your household income?

a. less than $12,000
b. $12,001-20,000
c. $20,001- $30,000
d. $30,001-$50,000
e. $50,001-$100,000
f. $100,001 and above
g. Do not want to reply

What is your occupation?

Job 1,specify_____
hours worked/week_____

Job 2, specify_____
hours worked/week_____

What is the occupation of your spouse or partner (anyone with whom you share your home)?

Job 1,specify_____
hours worked/week_____

Job 2, specify_____
hours worked/week_____

Children of Interviewee:

No. of children (<18 yrs) who live in home that go to the beach: _____

No. of children you typically take to the beach: _____

Relation of children to adult interviewee: Parent, Grandparent, Guardian, _____

Youngest to Oldest (for children that you have guardianship for) Enter in nearest years.
Child 1, Age___ Gender M/F
Child 2, Age___ Gender M/F
Child 3, Age___ Gender M/F
Child 4, Age___ Gender M/F
Child 5, Age___ Gender M/F
Child 6, Age___ Gender M/F
Child 7, Age___ Gender M/F

EXPOSURE ASSESSMENT

1. **Is your home in this State?** Y/N

2. **Where is your primary home residence?**
   City _____
   State_____
   Country _____

3. **How far are you staying from this beach?**
   a. Less than 5 miles
   b. 5 miles to less than 10 miles
   c. 10 miles to less than 20 miles
   d. 20 miles to less than 30 miles
   e. Greater than 30 miles

4. **How do you usually get to the beach?**
   a. Drive/car
   b. Walk
   c. Bus
   d. Other, specify _____

5. **During what time of year do you typically go to the beach?**
   a. All year long
   b. Summer
   c. Fall
   d. Spring
   e. Winter
   f. Other _____

6. **What impacts the day you decide to go to the beach with children?** Select all that apply.
   a. Children out of school
   b. Weather, sunny day
   c. Air temperature
   d. Water temperature
   e. Other _____

   If water temperature selected, what temperature ranges
   _____Water (˚F)
   _____Do not know

   If air temperature selected, what temperature ranges
   _____Air (˚F)
   _____Do not know

7. **What impacts the time of day you take the children to the beach?** Select all that apply.
   a. Sun intensity
   b. Heat
   c. Traffic
   d. Work/School Schedule
   e. Other _____

8. **How often do your children go to the beach on average?**
   a. Once a week or more
   b. Once a month or more
   c. Once a year or more
   d. Uncertain

9. **When you take your children to the beach, how long do you typically stay?**
   a. Less than 1 hour
   b. An hour to less than 2 hours
   c. 2 hours to less than 3 hours
   d. 3 hours or more
   e. Uncertain

10. **When you go by yourself or with another adult, how long do you stay on the beach?**
    a. Less than one hour
    b. An hour to less than 2 hours
    c. 2 hours to less than 3 hours
    d. More than 3 hours
    e. Uncertain
    f. Only go to beach with children

11. On a typical beach day do you bring the following? Select all that apply.
a. Toys _____
b. Animals/Pets _____
c. Additional friends
d. Other _____

For the following questions we are referring to your children under the age of 6 years. Select all that apply

12. At which areas do the children play? Select all the apply. (please note the intertidal wet sand area)

Child 1:
a. Dry Sand
b. Intertidal
c. Water
d. All
e. Uncertain

Child 2:
a. Dry Sand
b. Intertidal
c. Water
d. All
e. Uncertain

Child 3:
a. Dry Sand
b. Intertidal
c. Water
d. All
e. Uncertain

13. Please indicate the approximate percentage of time each child is typically engaged in:

Child 1: (should add up to 100%)
Dry sand play ____%
Play in the intertidal zone (wet sand) ___%
Play in the water____%
Other _____%

If they play in the sand, do they bury themselves? Y/N/sometimes/uncertain

Child 2:
Dry sand play ____%
Play in the intertidal zone (wet sand) ___%
Play in the water____%
Other _____%

If they play in the sand, do they bury themselves when they play in the sand? Y/N/sometimes/uncertain

Child 3:
Dry sand play ____%
Play in the intertidal zone (wet sand) ___%
Play in the water____%
Other _____%
If they play in the sand, do they bury themselves when they play in the sand?
Y/N/sometimes/uncertain

Child 4:
Dry sand play ____%
Play in the intertidal zone (wet sand) ___%
Play in the water____%
Other _____%
If they play in the sand, do they bury themselves when they play in the sand?
Y/N/sometimes/uncertain

Child 5:
Dry sand play ____%
Play in the intertidal zone (wet sand) ___%
Play in the water____%
Other _____%
If they play in the sand, do they bury themselves when they play in the sand?
Y/N/sometimes/uncertain

14. When they are playing with the sand, are they usually: Select all that apply

Child 1:
a. Sitting directly on sand
b. Sitting in chair
c. Rolling on sand
d. Digging
e. Making castles
f. Making pools
g. Other_____

Child 2:
a. Sitting directly on sand
b. Sitting in chair
c. Rolling on sand
d. Digging
e. Making castles
f. Making pools
g. Other_____

Child 3:
a. Sitting directly on sand
b. Sitting in chair
c. Rolling on sand
d. Digging
e. Making castles
f. Making pools
g. Other_____

Child 4:
a. Sitting directly on sand
b. Sitting in chair
c. Rolling on sand
d. Digging
e. Making castles
f. Making pools
g. Other_____

Child 5:
a. Sitting directly on sand
b. Sitting in chair
c. Rolling on sand
d. Digging
e. Making castles
f. Making pools
g. Other_____

15. What parts of their bodies are usually in contact with the sand? Select all that apply

Child 1:
a. Feet
b. Legs
c. Hands
d. Arms
e. Torso
f. Chest
g. Head
h. Face
i. _____

Child 2:
a. Feet
b. Legs
c. Hands
d. Arms
e. Torso
f. Chest
g. Head
h. Face
i. _____

Child 3:
a. Feet
b. Legs
c. Hands
d. Arms
e. Torso
f. Chest
g. Head
h. Face
i. _____

Child 4:
a. Feet
b. Legs
c. Hands
d. Arms
e. Torso
f. Chest
g. Head
h. Face
i. _____

Child 5:
a. Feet
b. Legs
c. Hands
d. Arms
e. Torso
f. Chest
g. Head
h. Face
i. _____

16. What do your children typically wear while they are playing on the beach? Select all that apply

Child 1:
a. Bathing trunks or shorts
b. Bikini bathing suit
c. One piece bathing suit
d. Shirt, short sleeve
e. Shirt, long sleeve
f. Hat
g. Water shoes
h. Diaper only
i. Other _____

Child 2:
a. Bathing trunks or shorts
b. Bikini bathing suit
c. One piece bathing suit
d. Shirt, short sleeve
e. Shirt, long sleeve
f. Hat
g. Water shoes
h. Diaper only
i. Other _____

Child 3:
a. Bathing trunks or shorts
b. Bikini bathing suit
c. One piece bathing suit
d. Shirt, short sleeve
e. Shirt, long sleeve
f. Hat
g. Water shoes
h. Diaper only
i. Other _____

Child 4:
a. Bathing trunks or shorts
b. Bikini bathing suit
c. One piece bathing suit
d. Shirt, short sleeve
e. Shirt, long sleeve
f. Hat
g. Water shoes
h. Diaper only
i. Other _____

Child 5:
a. Bathing trunks or shorts
b. Bikini bathing suit
c. One piece bathing suit
d. Shirt, short sleeve
e. Shirt, long sleeve
f. Hat
g. Water shoes
h. Diaper only
i. Other _____

17. Do your children typically put items in the mouth during their beach play?

Child 1:
a. Yes
b. No
c. Sometimes
d. Uncertain

If yes, what are the typical items_____
Does the child put it intentionally in their mouth or accidentally? intentional/accidental

Child 2:
a. Yes
b. No
c. Sometimes
d. Uncertain

If yes, what are the typical items_____
Does the child put it intentionally in their mouth or accidentally? intentional/accidental

Child 3:
a. Yes
b. No
c. Sometimes
d. Uncertain

If yes, what are the typical items_____
Does the child put it intentionally in their mouth or accidentally? intentional/accidental

Child 4:
a. Yes
b. No
c. Sometimes
d. Uncertain

If yes, what are the typical items_____
Does the child put it intentionally in their mouth or accidentally? intentional/accidental

Child 5:
a. Yes
b. No
c. Sometimes
d. Uncertain

If yes, what are the typical items_____
Does the child put it intentionally in their mouth or accidentally? intentional/accidental

18. Do your children like to collect items from the beach (these items may be shells, stones, sand, or other items)?

Child 1:
a. Yes
b. No
c. Sometimes
d. Uncertain

If yes, list items _____

Child 2:
a. Yes
b. No
c. Sometimes
d. Uncertain

If yes, which items _____

Child 3:
a. Yes
b. No
c. Sometimes
d. Uncertain

If yes, which items _____

Child 4:
a. Yes
b. No
c. Sometimes
d. Uncertain

If yes, which items _____

Child 5:
a. Yes
b. No
c. Sometimes
d. Uncertain

If yes, which items _____

19. Do you bring snacks or meals to the beach?
a. Yes
b. No
c. Sometimes
d. Uncertain

If snacks/food/drinks are available for purchase, do you purchase?
Y/N/sometimes/uncertain

Please describe the typical snacks/meals, and drinks (water, sodas)
_____

20. Do your children use sunscreen while they are at the beach?
Y/N/sometimes/uncertain

Do they reapply Y/N/sometimes/uncertain
If yes or sometimes, explain
_____

21. **If there are bathrooms at the beach...**

Do you stay at the beach longer?

Y/N/sometimes/uncertain
Do the children wash their hands before eating at the beach?
Y/N/sometimes/uncertain

22. If there are showers at your beach ...

Do you use the shower to rinse yourself?
Y/N/sometimes/uncertain
Do you use the foot rinse for the child?
Y/N/sometimes/uncertain
Do you use the shower for the child?
Y/N/sometimes/uncertain

23. Do you take soap to the beach?
a. Yes
b. No
c. Sometimes
d. Uncertain

If no or uncertain, skip to question 26

24. How often do you apply soap and water to your child's hands? Select all that apply
a. Every hour
b. Every couple hours
c. Before meals
d. Before going home
e. Never
f. Uncertain

25. How often do you apply soap and water to your hands? Select all that apply
a. Every hour
b. Every couple hours
c. Before meals
d. Before going home
e. Never
f. Uncertain

26. Do you go other places after the beach (i.e., shopping, restaurants)?
a. Yes
b. No
c. Sometimes
d. Uncertain

27. When you get home from the beach, do the children have a bath or shower?
a. Right away
b. Within an hour
c. Within a couple hours
d. Later that night
e. Next day
f. Uncertain

28. Do the children bath themselves or do you help them?

Child 1: themselves/help/both
Child 2: themselves/help/both
Child 3: themselves/help/both
Child 4: themselves/help/both
Child 5: themselves/help/both

29. When you help them bath, do you observe that they still have sand on their bodies?

Child 1: Y/N/sometimes/uncertain
Child 2: Y/N/sometimes/uncertain
Child 3: Y/N/sometimes/uncertain
Child 4: Y/N/sometimes/uncertain
Child 5: Y/N/sometimes/uncertain

RISK PERCEPTION

30. Do you believe that you or your children have ever gotten sick after a beach visit or within a couple days of a beach visit?
a. Yes
b. No
c. Maybe
d. Uncertain

If yes or maybe, can you describe the sickness?_____
_____
_____
_____

31. Do you believe it is possible to get sick after visiting the beach?
a. Yes
b. No
c. Maybe
d. Uncertain

If yes or maybe, what are the things that can make you sick after visiting the beach? Please list.
a. _____
b._____
c._____
d._____
e._____
f. _____

32. Do you typically see signs and postings on the beach area?
a. Yes
b. No
c. Maybe
d. Uncertain

33. Do you pay attention to signs and postings on the beach area?
a. Yes
b. No
c. Maybe
d. Uncertain

34. Have you ever heard warnings about safety and beach closings?
a. Yes
b. No
c. Maybe
d. Uncertain

If yes or maybe, where have you heard these warnings? Select all that apply.

a. Radio news
b. TV news
c. Postings on the beach
d. Schools
e. Newspapers
f. Social media, type: Facebook, Twitter, _____
g. Word of mouth
h. Cell-phone app with notifications
i. Other _____

35. From where would you prefer to get messages about beach safety and closings? Select all that apply.
a. Radio news
b. TV news
c. Postings on the beach
d. Schools
e. Newspapers
f. Social media type: Facebook, Twitter, _____
g. Word of mouth
h. Cell-phone app with notifications
i. Other _____

36. When you get notices are they easy to understand? Y/N/sometimes/uncertain

37. Do you have concerns when you visit the beach? Y/N/uncertain

If yes, what are the concerns

1. _____
2. _____
3. _____

38. Which of these would concern you more about visiting the beach? Please rank the following in terms of concern you may have when you visit the beach. Rank on a scale of 1 to 10, 1 being no concern and 10 being very concerning.

a. Infections (bacteria/viruses/parasites)____
b. Shark attacks_____
c. Strong waves_____
d. Rip tides _____
e. Hurricanes or strong storms_____
f. Chemical or oil spill_____
g. Other_____

39. If a beach looks dirty to you (i.e., appears to have some tar or oil), do you let your children go there?
a. yes
b. no
c. sometimes
d. uncertain

40. What will make the beach look dirty? Select all that apply.
a. Seaweed
b. Some tar or oil
c. Trash
d. Other _____

41. Have you ever observed oil stains on your children after they play at the beach? Y/N/sometimes/uncertain

If yes, describe how much of their skin had an oil stain?_____

42. Are you familiar with tarballs? Y/N/maybe/uncertain

Tarball definition: dark or black/brown pellets or chunks, that might be indicative of the presence of oil. May look like a small piece of roadway asphalt. PHOTO CAN BE SHOWN.

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