EXECUTIVE SUMMARY

Technical toxaphene, a broad spectrum organochlorine insecticide, was produced by Hercules Inc. in Brunswick (GA) for more than 30 years. Because several public access areas including schoolyards are in close proximity to the plant, concerns over human health risks from toxaphene contamination in soils have been raised. Previous studies have been inconclusive as to the levels and extent of toxaphene contamination in local schoolyard soils. The objective of this study was to determine if toxaphene contamination in soils from Goodyear and Burroughs-Molette Elementary Schools, Risley Middle School, and the Edo Miller/Lanier Field Recreational Area -- poses a potential human health risk.

A total of 94 surface soil samples were collected in Spring 2002 and analyzed for toxaphene using two analytical methods. A commercially available, enzyme-linked immunosorbent assay (ELISA) kit was used to semiquantitatively classify toxaphene concentrations. A sample subset (n=36) was analyzed by gas chromatography with electron capture and mass spectrometric detection (GC-ECD and GC-MS, respectively). In addition to toxaphene, concentrations of other organic chemicals of environmental concern (chlorinated pesticides, PCBs and PAHs) were determined by GC.

Based on ELISA, well over half the soil samples contained low amounts of toxaphene (<2 ppm). More than half of Goodyear Elementary School soils (56%) were classified as moderately to highly contaminated (>2 ppm) with a single sample classified as highly contaminated (>10 ppm). Roughly one quarter of Risley MS samples were in the moderate range (2<x<10 ppm). All soils from Burroughs Molette Elementary School and Edo Miller/Lanier Field Recreational Area were classified as low or undetectable (<2 ppm).

Less than a third (10 of 36; 28%) soil samples analyzed by GC had detectable levels of toxaphene. Total toxaphene (ΣTOX) in these samples ranged from 0.02 to 0.38 ppm. In contrast, nearly all samples contained detectable levels of PAH, PCB and chlordanes with maximum concentrations of 22, 0.064 and 0.79 ppm, respectively. Linear regression analyses indicated that Σchlordane was highly correlated with modeled ELISA concentrations (R^2=0.57), whereas ΣPAH and ΣPCB were not. Confirmational GC-MS analyses clearly indicated that chlordanes – and not toxaphene -- were the predominant class of organochlorine contaminants in these samples, including the single Goodyear ES sample classified by ELISA as highly contaminated (>10 ppm) with toxaphene.

Because cyclodiene pesticides including chlordane are similar in chemical structure to toxaphene, the ELISA test kit utilized in this study is subject to interference. The presence of chlordane residues at or above the test kit interference threshold coupled with low or undetectable levels of toxaphene by GC indicates that toxaphene is unreliably quantified (and overestimated) by ELISA in these samples. Furthermore, toxaphene levels as determined by GC are well below soil thresholds (~1 ppm) at which human health risks are deemed unacceptable.

1. INTRODUCTION

1.1 DEFINITIONS

Technical toxaphene (or "TTX"), a widely used pesticide, is a complex mixture of individual polychlorinated monoterpene (bornane, camphene and dihydrocamphene) compounds (or "congeners") with 6-10 chlorines per molecule and an average chlorine content of 68-70% [1]. Because of its persistence and potential for toxicity, toxaphene and its residues continue to pose a threat to ecological and human health. With several thousand compounds theoretically possible, it is thought that the technical mixture of toxaphene consists of several hundred congeners, making the analysis of toxaphene residues in environmental samples a challenging task [2]. Because components in TTX are selectively transformed in the environment, *toxaphene residues* (or simply "toxaphene") are defined as original TTX components and transformation products thereof.

1.2 TOXAPHENE PRODUCTION AND USAGE

Hercules Inc. in Brunswick, GA produced technical toxaphene from the late 1940s until 1980. During this period, it was used primarily as an agricultural pesticide, with applications on soybeans, wheat, cotton, and peanuts. This biocide was also used as a de-licer for livestock and to clear lakes of unwanted fish. During the late 20th century, toxaphene was one of the most heavily used chlorinated pesticides worldwide, with a global production since 1950 estimated at more than 1 megatons [3]. Although banned in the U.S in 1982, residues of toxaphene are transported via the atmosphere and as a result are detectable in polar as well as temperate ecosystems. Similar to other pollutants like DDT, polychlorinated biphenyls (PCBs) and other organochlorines, toxaphene was found in air, fish, marine biota, foods, human milk and even Arctic animals [4,5]. Nonetheless, toxaphene and similar products are still produced and used in some third world countries.

1.3 PHYSICAL AND CHEMICAL PROPERTIES

TTX was produced by isomerization of α-pinene to α-terpineol, bornylene, and camphene, followed by exhaustive chlorination using chlorine gas in the presence of ultraviolet radiation. Chlorinated monoterpenes (e.g. bornenes and camphenes) are formed during this process, but the majority of TTX components are based on the bornane skeleton (Fig. 1). TTX is a yellow, waxy solid at room temperature, with a mild terpene odor. It is readily soluble in most organic solvents, but it is more soluble in aromatic than in aliphatic hydrocarbon solvents. The average elemental composition of TTX is $C_{10}H_{10}Cl_8$ and its several hundred components are represented by the formulas $C_{10}H_{18-n}Cl_n$ or $C_{10}H_{16-n}Cl_n$, where n is 6 to 10 [1]. TTX is relatively stable but may be degraded by continued exposure to sunlight, alkali, or temperatures above 393K [6]. A specific gravity of 1.6 kg liter^{-1} has been reported for technical toxaphene [7]. Vapor

pressure and the log octanol-water partition coefficient (K_{ow}) value are comparable to that of hexachlorobenzene (HCB), 1.73×10^{-3} Pa at 298K [8], and a log K_{ow} of 5.5 [9].

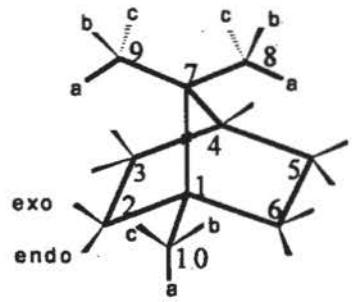


Figure 1. Bicyclic monoterpene (bornane) skeleton of toxaphene. Numbers represent IUPAC carbon numbering scheme; small case letters represent the conformational position of Cl or H atoms.

1.4 Fate and Effects

Wania and Mackay [10] reported that toxaphene is largely associated with aerosols in the atmosphere, and is thus removed by both wet and dry deposition. Moreover, toxaphene is transferred more rapidly from the atmosphere to soil and water at low temperature [2]. In warmer climates, evaporation from soils and surfaces will be a significant process. Toxaphene in soil can persist for long periods (1 to 14 yr) and is not expected to leach significantly into groundwater or be mobilized in runoff unless adsorbed to clay particles. In anaerobic soils and sediments, biotransformation of toxaphene results in the formation of lower chlorinated homologs [11]. Primary dechlorination products are 2-*exo*,3-*endo*,6-*exo*,8,9,10-hexachlorobornane (B6-923 or "Hx-Sed") and 2-*endo*,3-*exo*,5-*endo*,6-*exo*,8,9,10-heptachlorobornane (B7-1001 or "Hp-Sed"). Levels may be high in fish [12] and mammals [13] because toxaphene accumulates in fatty tissues. Several components resist environmental degradation, including those found in polar wildlife [4].

Toxaphene is classified by EPA as a persistent, bioaccumulative and toxic chemical of primary concern [14], and is listed as a probable carcinogen [15] based on experiments in mice and in rats [1]. For example, a dose-related increase in the incidence of hepatocellular carcinomas was observed in male and female mice exposed to toxaphene via oral administration. In addition, an increased incidence of thyroid tumors was observed in male and female rats. Toxaphene was also found to elicit mutagenic properties in the bacterium *Salmonella typhimurium*. It is acutely and chronically toxic to aquatic organisms and wildlife at parts per billion concentrations. Neurotoxic, behavioral and learning effects due to toxaphene exposure have been reported (Table 1). Histological changes in the brain of guinea pigs -- disorganization and enlargement changes in the neutron -- after exposure to toxaphene has been reported [16].

Table 1. Neurologic and development effects associated with toxaphene exposure.

In vivo Species	Route/ Duration	Dose, mg $kg^{-1}day^{-1}$	Type of effects	Effect
Rat	Oral/3days, 1x/day	25	Neurologic	Tremors, nervousness
Guinea pig	Oral/once	300	Neurologic	10% decreased brain weight
Dog	Oral/2days	10	Neurologic	Convulsions, salvation, vomiting
		5	Neurologic	No body weight gain
Rat	Ad lib/14days	10	Development	No body weight gain
Rat	Oral/gestation day 7-16, 1x/day	12.5	Development	Decreased fetal renal protein
Mouse	Oral/gestation day 7-16, 1x/day	35	Development	No body weight gain

data from [1]

Human exposure to toxaphene residues can occur via several pathways. For example, consumption of contaminated fish, exposure in the workplace, breathing of airborne toxaphene, or contact via contaminated soils are all possible exposure routes. There exist however little data on the risk to humans from toxaphene exposure [1]. Brown et al. [17] and Cantor et al. [18] reported an association between elevated risk of leukemia and non-Hodgkin's lymphoma (NHL) among farmers that were exposed to pesticides and other agricultural chemicals. The risk increased for farmers who worked with pesticides without protection. Some of the chemicals with risk of NHL were carbaryl, chlordane, DDT, diazinon, lindane, nicotine, and toxaphene. The International Agency for Research on Cancer (IARC) regards toxaphene as a carcinogenic risk to humans based on studies with mice and rats, despite the deficiency of adequate data for humans [15]. In contrast, de Boer and Wester found no correlation between the number of children borne and toxaphene levels in mother's milk [5].

1.5 Other Pesticides

1.5.1 Chlordane

Chlordane is the generic name of a technical biocide mixture consisting of several (10 major) components that are structurally related to toxaphene. Technical chlordane was used in the United States from 1948 to 1988. Two of the major components are α- and γ-isomers of chlordane, whose molecular formula is $C_{10}H_6Cl_8$. The IUPAC name for chlordane is 1,2,4,5,6,7,8,8-Octachlor-2,3,3a,4,7,7a-hexahydro-4,7-methanoinden (Fig. 2). Other major components are β-chlordane, heptachlor, and trans-nonachlor.

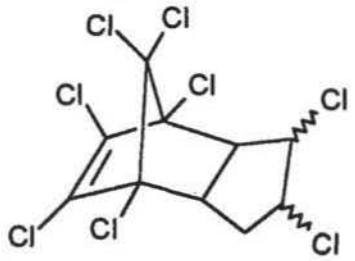
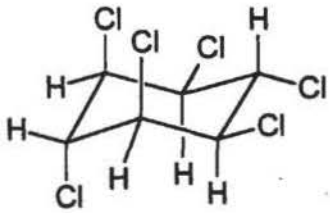


Figure 2. Chlordane, a mixture of chlorinated cyclodiene compounds.

Chlordane was used to control insects on agricultural crops, lawns, and gardens. It was also used as a fumigant and to control termites. Because of concerns over cancer risk, evidence of human exposure and accumulation in biological lipids, persistence in the environment, and potential toxicity to wildlife, the EPA canceled the use and manufacture of chlordane in 1988. Chlordane is stable in the environment for many years and is ubiquitous in food, air, water, and soil. Major transformation products of chlordane in the environment are oxychlordane and heptachlor epoxide. Chlordane residues are commonly found in all compartments of the environment, including humans.

1.5.2 HEXACHLOROCYCLOHEXANES (HCHs)

Hexachlorocyclohexanes (HCH) are a group of manufactured chemicals with eight possible isomers (Fig. 3). Technical grade HCH is composed of the four most common isomers: α–, β–, γ- (Lindane), and δ-HCH. Lindane, the most biologically active isomer, is a white solid substance that may evaporate into the air as a colorless vapor with a slightly musty odor. Lindane was used as an insecticide on vegetable crops and fruit and forest crops. It remains in use in ointments to treat scabies and head and body lice. Lindane has not been produced in the United States since 1977, however, it is still imported into the U.S.



γ-HCH

α-HCH aaeeee u. aeeeea 160°
β-HCH eeeeee 309°
γ-HCH aaaeee 114°
δ-HCH aeeeee 139°
ε-HCH aeeaee 219°
η-HCH aaeaee 90°
φ-HCH aeaeee 125°

Figure 3: HCH structure and isomers

1.5.3 Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are fused (2-6) ring structures formed during the incomplete burning of wood, coal, gas, oil, garbage, or other organic substances (Fig. 4). Some PAHs are thought to have biogenic origins. They can also be found in crude oil, coal, coal tar pitch, creosote, and roofing tar. They are ubiquitous contaminants in all major compartments of the environment. Although the health risks posed by individual PAHs may vary widely, several are considered as carcinogenic or as probable carcinogens (Table 2).

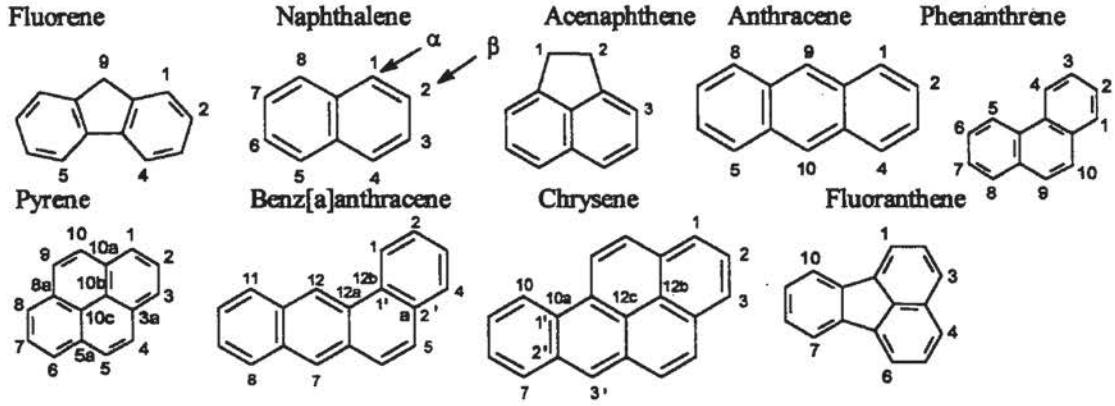


Figure 4. Structure of PAHs commonly found in the environment.

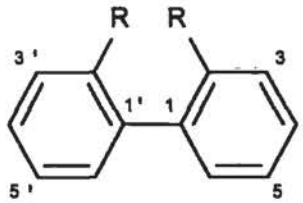
Table 2. PAHs of environmental concern.

Acenaphthene	Benzo[k]fluoranthene
acenaphthylene	Chrysene
anthracene	Dibenz[a,h]anthracene
benz[a]anthracene	Fluoranthene
benzo[a]pyrene	Fluorene
benzo[e]pyrene	indeno[1,2,3-c,d]pyrene
benzo[b]fluoranthene	Phenanthrene
benzo[g,h,i]perylene	Pyrene
benzo[j]fluoranthene	

PAHs enter the atmosphere via forest fires, volcanic emissions, residential wood burning, and combustion engine exhaust. The distribution of PAHs in the environment depends on individual physicochemical properties such as vapor pressure and water solubility. PAHs with > 4 rings are very hydrophobic and nonvolatile. As a result, they are associated with atmospheric particles (e.g. smoke) or soils and sediments with elevated organic matter content. PAHs accumulate in plants and animals, but are in general metabolized by higher organisms. PAHs are also subject to microbial degradation as well as sunlight (UV) induced transformation. Environmental half lives are generally proportional to the number of rings.

1.5.4 Polychlorinated Biphenyls (PCBs)

PCBs are a class of 209 individual chlorinated compounds with no known natural source. Commercial mixtures produced in the U.S. are known primarily by the trade name Aroclor. Percent chlorine by mass in Aroclor mixtures ranges from 16 to 68%.



R = H : Biphenyl
R = OH : 2,2'-Biphenyldiol
R = COOH : Diphenacid
R = Cl : PCB

Figure 5. Generic structure of PCBs.

PCBs were used as coolants and lubricants in transformers, hydraulic oils, capacitors, and other electrical equipment because of their dielectric properties, and chemical stability and inertness. PCB manufacture ceased in the U.S. in 1977 due to evidence of accumulation in the environment and concerns over environmental and human health effects. PCBs are stable in the environment and like other hydrophobic organic compounds, have low water solubility and vapor pressure. They accumulate in soils, sediments and biological compartments and exhibit biomagnification in terrestrial and aquatic food webs. The most commonly observed health effects in people exposed to elevated PCBs are skin conditions such as acne and rashes. Studies in exposed workers have shown changes in blood and urine that are suggestive of liver damage. Animals exposed to highly contaminated food over relatively short periods of time exhibited liver damage and in some cases mortality. Animals surviving chronic exposure to PCBs developed various kinds of health effects, including anemia, acne-like skin conditions, and liver, stomach, and thyroid injuries. Other effects of PCBs include changes in the immune system, behavioral alterations, and impaired reproduction. Few studies of workers indicate that PCBs were associated with certain kinds of cancer in humans, such as cancer of the liver and biliary tract. Because rats exposed to high levels over two years developed liver cancer, PCBs are considered probable carcinogens.

1.6 Analytical Methods For Toxaphene

1.6.1 Immunoassays

Immunoassays were developed in the 1960s for the identification and localization of antigens in histological preparations. Immunoassays take advantage of specific interactions between antibodies and antigens to measure a variety of substances. Antibodies are proteins produced by lymphocytes (white blood cells) in response to infection caused by a foreign substance (antigen) in order to render it harmless. Production of antibodies can be induced by directly immunizing a vertebrate species (e.g.

rabbits or sheep). Antibodies produced *in vivo* are polyclonal, i.e. they reflect the entire immune response [19]. Monoclonal antibodies can also be produced artificially and subsequently isolated for various uses. For example, mouse lymphocytes producing the required antibody are fused with mouse cancer cells. The resulting hybrid cells produce the same type of antibody as their parent lymphocytes. Monoclonal antibodies prepared in this fashion are widely used to detect and quantify levels of antigens. Commonly used immunoassays are competitive or non-competitive.

1.6.1.1 Competitive Immunoassays

Competitive assays use a single specific antibody type immobilized onto a solid surface. A corresponding analogue of the analyte, e.g. an antigen, is labeled with an enzyme such as alkaline phosphatase. When incubated together, the analyte or antigen in the sample "competes" with the labeled analogue for binding to the antibody. After separation of unbound analogue, the amount of label remaining is measured and the resulting signal is inversely proportional to the amount of antigen in the sample. Competitive assays are compatible with a wide range of analytes and are used for the majority of low molecular weight organic analytes (i.e. contaminants) of environmental and food safety concern.

1.6.1.2 Non-Competitive ("Sandwich") Immunoassays

Non-competitive assays utilize two specific antibodies to "sandwich" the analyte. One antibody is immobilized to a solid surface and the second antibody carries the label. In the assay, analyte is bound simultaneously by both the capture and label antibodies. After separation of unbound label antibody, the remaining label is measured and is directly proportional to analyte concentration in the sample. Sandwich assays are limited to those analytes of sufficient size to be able to bind two antibodies simultaneously, typically proteins and microorganisms [19].

1.6.1.3 Detection and Measurement

Immunoassays most commonly utilize radioactivity, colorimetry, fluorescence, and chemiluminescence as detection methods. Early immunoassays used radioactive tracers. Non-radioactive detection in immunoassays began in the 1970's with the advent of colorimetry, normally by attachment of an enzyme to an antigen for the competitive methods, and attachment to a specific antibody for non-competitive assays. Entire enzyme systems like horseradish peroxidase (HRP) or alkaline phosphatase (AP) liberate a colored product after incubation with a suitable substrate. The amount of color generated is then measured at a specific wavelength. The optical density obtained is then related back to the concentration of the antigen in the sample. For better sensitivity and/or more rapid results, fluorometric or chemiluminescent detection can be substituted.

1.6.1.4 Enzyme Linked Immunosorbent Assay (ELISA)

The enzyme linked immunosorbent assay (ELISA) has become a commonly used method to detect organic contaminants in environmental samples. The basic steps of ELISA are as follows:

- Immobilization
- Competition
- Separation
- Substrate reaction
- Stop reaction
- Detection

Test kits based on the use of antibodies that specifically or selectively bind the analyte (or analyte-enzyme conjugate) of concern are commercially available. Antibodies are immobilized on the walls of plastic test tubes. When an analyte is present in the sample, it competes with the enzyme-conjugate, which are analogues of the analyte, for a limited number of binding sites (i.e. immobilized antibodies). After binding reactions are complete, unbound molecules are removed, usually by washing. A colorless solution of chromogenic substrate is then added to the test tube. In the presence of bound analyte-enzyme-conjugate, the colorless substrate is converted to a colored solution. The reaction is then ceased and the color intensity determined with a pre-calibrated spectrophotometer.

1.6.1.5 Interferences

Immunoassays including ELISA kits are subject to interference from compounds that are structurally similar to the target analyte. Although antibody-antigen reactions may be highly specific, they do not necessarily distinguish between compounds of the same or similar chemical structures (e.g. chlordane and toxaphene). Thus, the detection level of the target analyte is dependent on the presence and concentrations of interfering compounds.

1.6.2 Gas Chromatography (GC)

Gas chromatography (GC) is a technique of chemical separation of one or more individual compounds between two phases. One phase is fixed and called the stationary phase. The other is the mobile phase, which flows over the stationary phase. The components enter the stationary phase through the injector and move along the column at different rates. The lower the vapor pressure of the compound, the longer the compound will remain in the stationary phase. The time that each compound is retained on the fixed phase depends on the solubility of the compound in the stationary phase and the vapor pressure of the compound. Once eluted from the column, each compound is detected and its signal amplified and/or processed. The most important concept for the separation is that "likes dissolves likes". Thus, non-polar compounds are best separated using a non-polar stationary phase.

1.6.2.1 Electron Capture Detection (ECD)

Because toxaphene is highly chlorinated, the most widely used GC method is with electron capture detection (ECD). For example, EPA Method 8081 utilizes GC-ECD for a large number of chlorinated hydrocarbon analytes, including toxaphene [20]. Although ECD provides excellent sensitivity for these compounds, it is subject to interference from

a large number of halogenated and non-halogenated compounds alike. For example, the co-occurrence of toxaphene and PCBs in sediment and fish tissues from the Turtle/Brunswick estuary prevents accurate quantification of either contaminant by ECD without pre-separation [21,22].

1.6.2.1.1 TOXAPHENE TASK FORCE (TTF) METHOD

In an effort to standardize the approach and protocols for analyzing and reporting toxaphene levels in contaminated environmental media, a group known as the "Toxaphene Task Force" (TTF) developed a method based on GC-ECD [23]. This approach, known as the TTF method, requires the presence of four late eluting peaks in the ECD chromatogram in proportions similar to that found in unmodified (i.e. virgin) TTX. Environmental samples not meeting these criteria are assigned "not detected" (nd), regardless of the complexity and/or peak magnitude associated with the chromatogram.

1.6.2.2 ELECTRON CAPTURE NEGATIVE ION MASS SPECTROMETRY (ECNI-MS)

Mass spectrometry operating in the electron capture negative ion (ECNI-MS) mode offers excellent sensitivity and selectivity for chlorinated hydrocarbons such as toxaphene. When bombarded by a moderating ion, neutral toxaphene residue congeners capture an electron and thus become negatively charged, resulting in the formation of fragment ions (e.g. $[M\text{-}Cl]^-$). The simplicity of this fragmentation results in excellent sensitivity since only 1 or 2 ions can be monitored in the selected ion monitoring (SIM) mode. Pre-separation of PCBs prior to GC-ECNI-MS analysis minimizes the possibility of interferences or misidentification [24]. Whereas ECNI-MS readily confirms the identification of prominent target analytes, it is prone to response instability, and is thus less well suited than ECD or electron ionization MS for accurate quantification.

1.6.2.3 TWO DIMENSIONAL GC

Combining the best attributes of GC-ECD and ECNI-MS greatly reduces the uncertainty associated with non MS techniques in positively identifying toxaphene residues while retaining the response stability of ECD for quantification purposes. This approach, although costly and time consuming, has proven superior in determining the extent and congener distribution of toxaphene contamination in the Terry/Dupree Creek area of St. Simons Sound, GA [21,22,25]. This is particularly true for samples (i) where PCB interferences have largely been eliminated by pre-separation; and (ii) that have several fold higher levels of toxaphene relative to other organohalogen contaminants.

1.7 POTENTIAL RISKS ASSOCIATED WITH TOXAPHENE CONTAMINATED SOILS

Because toxaphene has been associated with neurotoxic and other deleterious effects on behavior and learning [2], the Glynn Environmental Coalition (GEC) has expressed concerns over the potential for human health risks at Glynn County schools. A review of historical records revealed that fugitive emissions of dust and dirt from the Hercules plant

in the city of Brunswick have been reported [26]. Soil within one half mile of the plant was expected to have 1 to 5 ppm toxaphene [27]. Moreover, Glynn County Schools were reported to have purchased toxaphene for use on parks, schools and recreational areas, including Edo Miller Recreational Area/Lanier Field [28].

Previous studies of schoolyard soils in the area used various methods to analyze for toxaphene and its environmental residues. The previously described TTF method has been used extensively in recent years [29]. Due to the omission of chemical compounds that elute in the toxaphene window or that are thought to be toxaphene related in GC chromatograms, however, this method is prone to underestimation of toxaphene residues in various environmental media [22,30-36]. Analysis of soils by EPA Method 8081 detected higher levels of toxaphene residues than the TTF method [31]. The TTF method failed to detect toxaphene residues at levels estimated up to 28 ppm in fish [22]. Analytical methods that estimated "total toxaphene" detected levels at Goodyear and Burroughs-Molette Elementary Schools that exceeded the 0.54 ppm screening level for carcinogenic risk, as well as the 10.88 ppm Georgia Environmental Protection Division reporting threshold [37]. Issues identified with the TTF method -- the data source for health consultations and human health risk assessments for citizens in the impacted area -- left community members questioning the validity and relevance of such assessments [22,37,38].

1.7.1 Previous Soil Investigations

In 1996 and 1997, Atlanta Testing and Engineering (AT&E) analyzed soil samples, conducted toxicity tests, and performed a risk assessment for 2 of the sites assessed in this study -- Goodyear and Buroughs-Molette Elementary Schools. Total toxaphene concentrations were estimated at 439 and 313 μg/kg (1 μg/kg = 1 part per billion or ppb) in single soil samples from Burroughs-Molette and Goodyear, respectively [39]. AT&E concluded that the schools had been impacted by toxaphene and recommended further investigation of the schoolyard surface soils [40]. Fourteen additional soil samples were then collected by AT&E and analyzed in accordance with EPA Method 8081 "total area" quantification protocols [41]. The range of toxaphene concentrations estimated in soil was 7180 to 64,600 μg/kg at Goodyear ES, and 614 to 13,000 μg/kg at Burroughs-Molette ES. Late in 1996, 40 additional samples were collected and analyzed for toxaphene, with six soil samples also tested for toxicity using the crustacean *Ceriodaphnia dubia* and the fathead minnow *Pimephales promelas* [41,42]. Toxaphene in soil ranged from 132 to 2145 μg/kg for Burroughs-Molette ES, and between 370-3870 μg/kg for Goodyear ES. Toxicity results revealed acute toxicity from 1 of the 6 soil samples taken at Goodyear ES [43]. As a result, it was suggested that cancer risk for students exceeded the baseline 1 in 1,000,000 based on a cumulative 180 days per year, 6 year exposure [39]. This risk assessment did not account for exposure to toxaphene via other pathways, (i.e. airborne, consumption of contaminated water or seafood) or during time spent outside of the school environment. Final corrective action recommendations by AT&E and the School Board's consultant were for the schoolyards to be covered with a layer of soil to prevent contact with contaminated soils by children [44-46].

2. METHODS

2.1 Reagents, Solvents, and Glassware

All chemical reagents and organic solvents used in this venture were of high purity (Optima or ACS reagent grade, Fisher Scientific Fair Lawn, NJ). Hydromatrix and Ottawa sand for the soil extraction were pre-extracted in a Soxhlet apparatus with ~400 ml of CH_2Cl_2. Florisil© (60-100 mesh) for extract fractionation was activated at 550°C in a muffle furnace for 24 h prior to deactivation with 1.0% hexane-washed water. All glassware was exhaustively detergent and water washed, kiln-fired at 650°C for > 8 h and rinsed with acetone and hexane prior to use.

2.2 Study Sites and Design

The following 4 public access areas in Brunswick, Georgia (USA) were chosen as sites for this study:

- Goodyear Elementary School (GYES)
- Burroughs-Molette Elementary School (BMES)
- Risley Middle School (RMS)
- Edo Miller/Lanier Field (EM/LF) Recreational Area

Prior to sampling, a grid network was superimposed on scaled plan views of each site. Individual sampling grids were 100 by 100 foot squares; in some cases, 200 to 100 foot grids were created. Each grid was given a numeric identifier (Figs. 6-9). Sampling grids with greater than 50% impervious surface coverage (e.g. school buildings, parking lots, sidewalks) were combined with an adjacent grid.

2.3 Soil Collection and Preservation

Prior to soil collection, sampling grid boundaries were marked off with rope and wooden stakes. In each grid, five surface soil grab samples to a depth of 3 inches were collected with a iron bulb planter (3" dia hollow iron cylinder). All grab samples were mixed thoroughly with a stainless steel spoon in an aluminum pan. Approximately 80g of homogenized soil from each grid was transferred into a pre-labeled 125ml clear glass I-Chem jar. Between samples, all sampling implements were wiped with a clean paper towel, rinsed with water followed by methanol and air-dried. Jars containing soil were kept cool and out of direct sunlight. Upon return to the lab, all sample jars were kept at 4°C in the dark for a maximum of 3 days prior to analysis.

2.3.1 Goodyear Elementary School

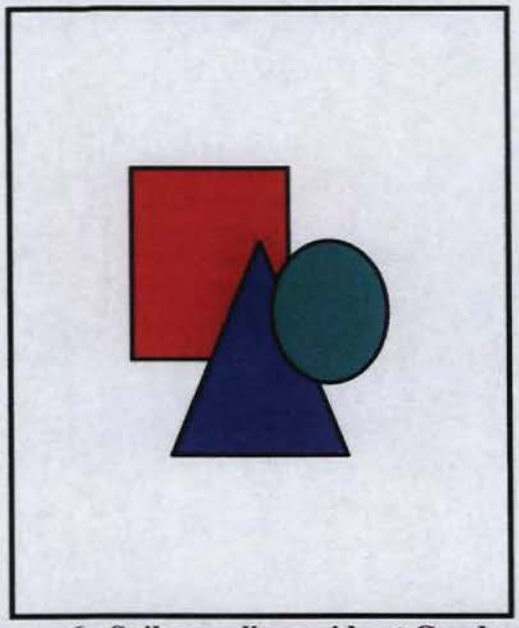


Figure 6. Soil sampling grids at Goodyear Elementary School.

2.3.2 Burroughs-Mollette Elementary School

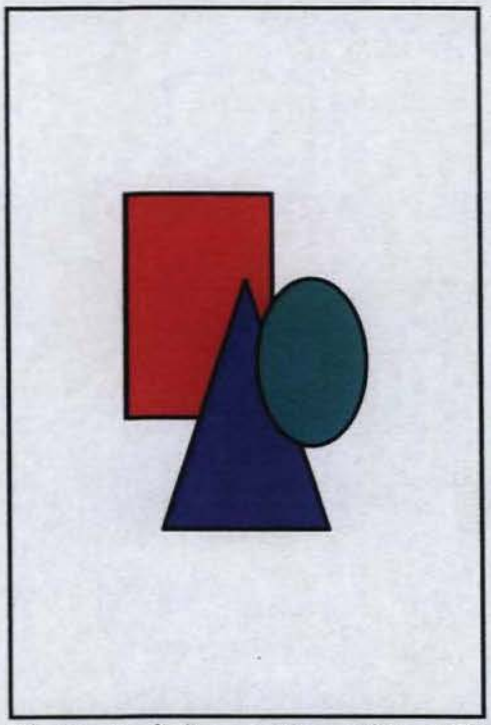


Figure 7. Soil sampling grids at Burroughs-Molette Elementary School.

2.3.3 Risley Middle School

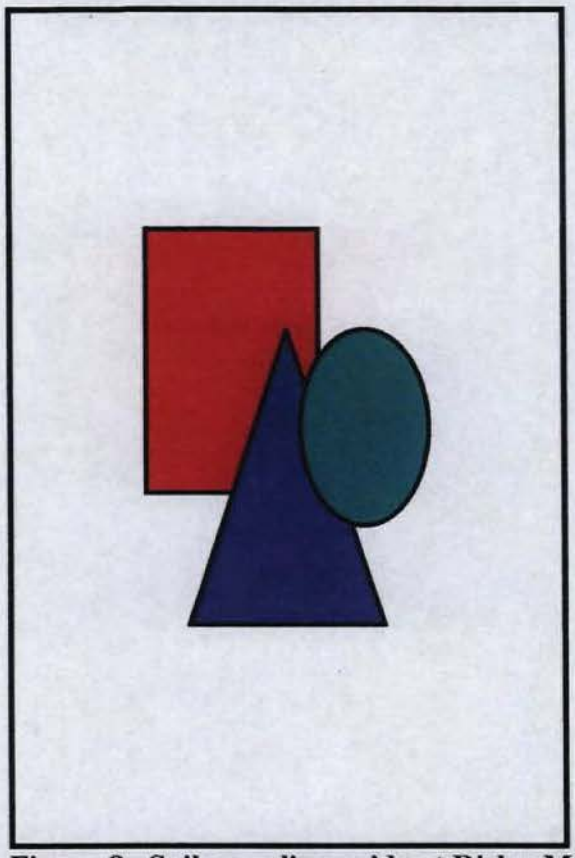


Figure 8. Soil sampling grids at Risley Middle School.

2.3.4 Edo Miller/Lanier Field, Recreational Area

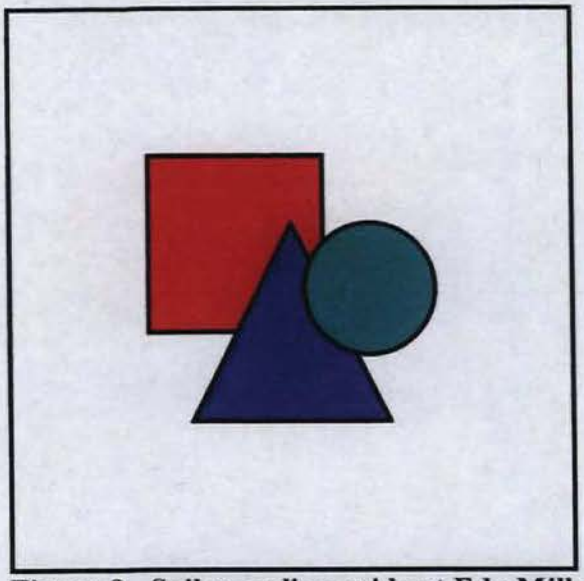


Figure 9. Soil sampling grids at Edo Miller/Lanier Field Recreational Area.

2.4 ELISA -- TOXAPHENE IN SOIL TEST KIT

EnviroGard™ Test Kits for Toxaphene in Soil and Extraction Test Kits were purchased from Strategic Diagnostics Inc. (Newark, DE, USA). Soil samples were extracted with a methanolic solution, filtered and assessed by ELISA using the SDI Toxaphene in Soil Test Kit in accordance with vendor instructions (Fig. 10).

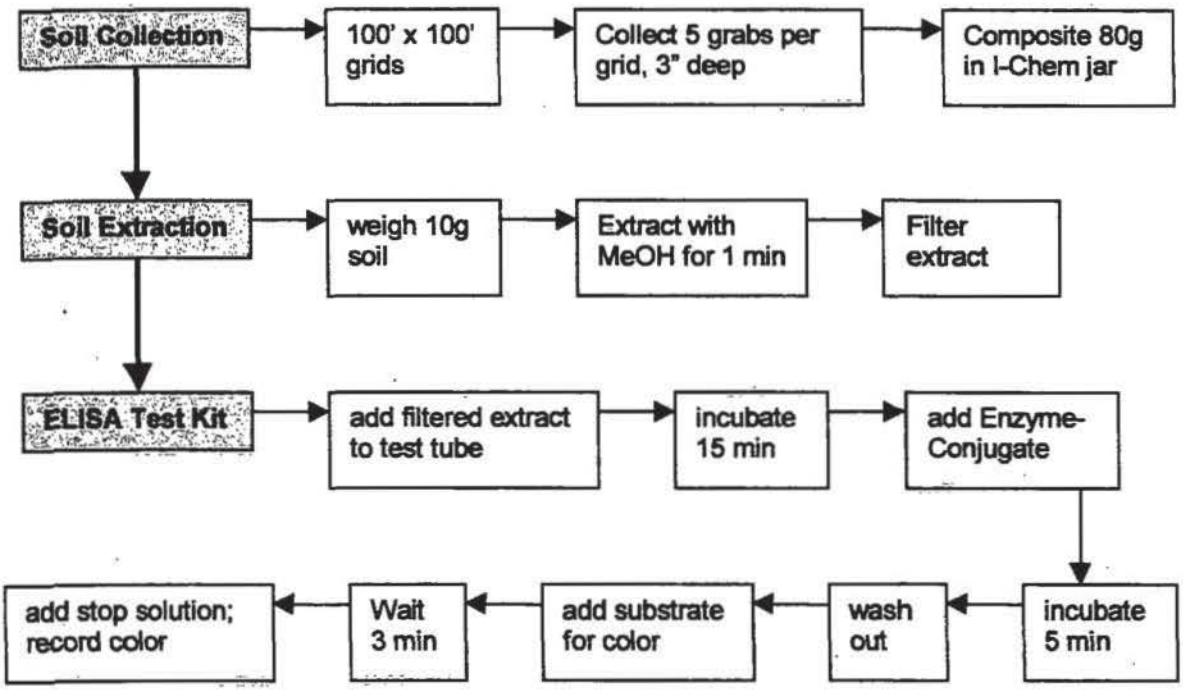


Figure 10. Schematic for analysis of toxaphene in soils using ELISA.

2.4.1 SAMPLE EXTRACTION

Fifteen (15) EnviroGard Toxaphene Soil Extraction Kits (SDI) were purchased from SDI (catalog no. 74200000EA). Ten gram aliquots of soil were extracted in accordance with the instructions provided by with the Sample Extraction Kits:

- weigh 10.0 g soil (using a wooden spatula)
- label extraction jar with sample information
- transfer 10.0 g aliquot of soil into jar
- pour contents of extraction solvent ampule (20 ml 90% methanol) into jar
- shake jar vigorously for 1.0 min
- allow methanolic extract to settle for 1 min (maximum 15 min)
- transfer ½ bulb capacity of liquid extract into the bottom of the filtration unit
- assemble the filtration unit and extrude sample through the filter

2.4.2 TEST KIT

Twelve (12) EnviroGard™ Toxaphene in Soil Test Kits (catalog no. 7420000) were purchased from SDI. The vendor advertised this kit as a semiquantitative enzyme immunoassay for the detection of toxaphene in soil, with screening levels at 0.5, 2.0 and 10.0 μg/g = parts per million (ppm). The vendor also reports that toxaphene in soils can be detected with 95% confidence of no false negative at the specified action level [47].

The EnviroGard™ Test Kits use coated polystyrene test tubes as the sorbing component of the ELISA. The sample is added along with the analyte labeled with an enzyme to a disposable test tube. Analyte present in the sample competes with the labeled analyte for binding sites on the antibodies. This immunological reaction occurs for 5 to 30 minutes. The tube is then washed and a color-developing reagent is added. After a short incubation, the color production is stopped and stabilized with acid. Color development is inversely proportional to the pesticide concentration (darker color = lower concentration).

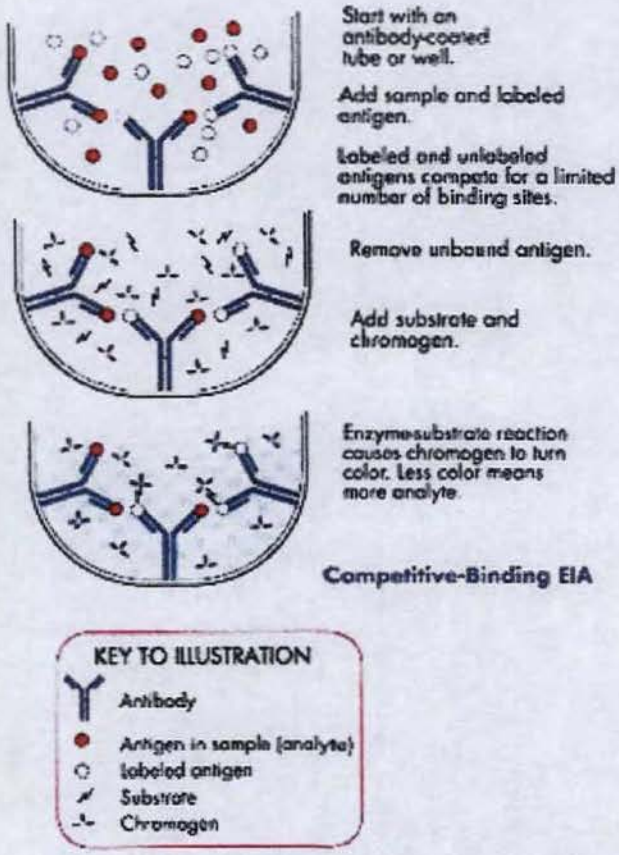


Figure 11. Toxaphene-enzyme specific interactions are measured colorimetrically using the Toxaphene in Soil ELISA Test Kit (SDI, Newark, DE).

2.4.2.1 PROCEDURES

- collect and extract soil sample (see section 2.4.1)
- add 250μL assay diluent to all test tubes
- using fresh pipette tips, add 50μL of each solvent to each test tube (including negative controls, pesticide calibrators)
- incubate tubes for 15 min
- add 200μL pesticide-enzyme conjugate
- gently shake test tube for 10-15 sec
- Leave tubes undisturbed for 5 min

- discard test tube liquid contents and wash out tube with cool tap/distilled water. Repeat three times. After final wash, remove as much water as possible
- add 500µL substrate to all test tubes
- briefly shake test tube rack and incubate for 3 min
- If the blue color does not develop in the negative control test tube within 3 min after addition of substrate, test is invalid
- add 500µL stop solution. Color will change from blue to yellow
- Record color intensity with a Varian Cary 3Bio dual beam UV-Visible spectrophotometer (λ=450nm) within 30 min

2.4.2.2 METHOD DETECTION LIMIT AND INTERFERENCES

The reported method detection limit (MDL) for toxaphene based on 10g soil extracted is 0.5 ppm. Semiquantitative concentration ranges of <0.5; 0.5<x<2.0; 2.0<x<10; and x>10 ppm were established based on 3 calibrator solutions per kit. In addition, other organochlorine biocides can interfere with Test Kit response (Table 3). Also shown is the compound specific concentration required to inhibit one-half of the color developed by the negative control (IC50).

Table 3. Summary of ELISA kit method detection limits (MDLs) for toxaphene and interfering organochlorine compounds [47].

Compound	MDL	IC50
Toxaphene	0.5ppm	2.8ppm
Endrin	3.9ppb	22ppb
Endosulfan I	6.4ppb	36ppb
Endosulfan II	5.0ppb	28ppb
Dieldrin	7.5ppb	42ppb
Heptachlor	6.1ppb	34ppb
Aldrin	20.7ppb	116ppb
Chlordane	17.9ppb	100ppb
Gamma-BHC	0.8ppm	4.6ppm
Alpha-BHC	3.4ppm	19ppm
Delta-BHC	7.1ppm	40ppm

2.5 GAS CHROMATOGRAPHY

A subset (n=36) of the 94 soil samples analyzed by ELISA were also analyzed by gas chromatography with electron capture and electron capture negative ion mass spectrometry (GC-ECD and GC-ECNI-MS, respectively). Samples were extracted with organic solvents, cleaned up and fractionated using Florisil column chromatography and reduced to ~1ml in hexane in preparation for GC analysis (Fig. 12). Comprehensive, performance based quality assurance/quality control measures were implemented to ensure data of the highest quality.

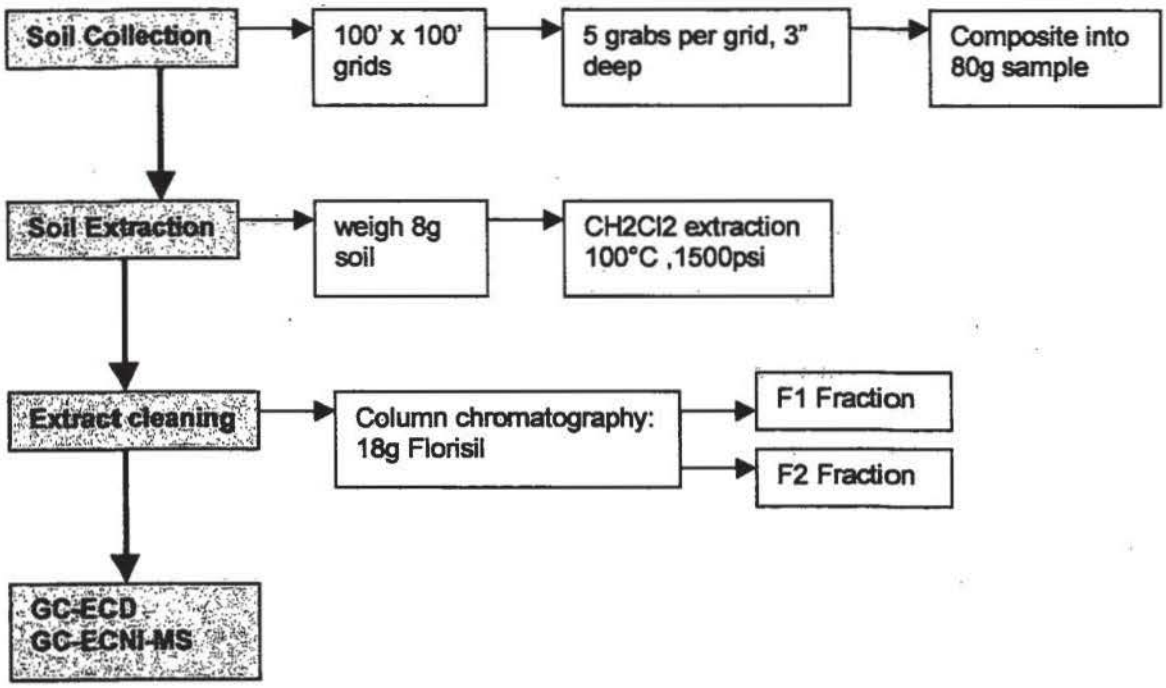


Figure 12. Sample processing schematic for GC analysis.

2.5.1 Soil Extraction

Eight grams of soil was homogenized with 4 g pre-extracted Hydromatrix and packed into stainless steel extraction cells. Pre-extracted Ottawa sand was added to completely fill the extraction cell. Dibromooctafluorobiphenyl (DBOFB) and α-HCH were then added to the top of each packed sample to track analyte recovery. Cells were then extracted using a Dionex Accelerated Solvent Extraction (ASE) 200 system with 90% CH_2Cl_2/10% methanol (v/v) heated to 100°C and pressurized to 1500 psi. ASE extracts were reduced to ~1ml and solvent exchanged to with hexane using a TurboVap II (Zymark Inc., Hopkington, MA). Hexane extracts were then applied to a glass column (500 mm L x 11 mm OD) dry packed with 18.0 g of 1.0% water deactivated Florisil. Two fractions were collected, the first fraction ("F1") was eluted with 90 ml hexane, and the second ("F2") was eluted with 150 ml of 20% CH_2Cl_2/80% hexane (v/v) to capture toxaphene residues. Both fractions were reduced and F2s exchanged to hexane using a TurboVap II. Water bath temperature and N_2 (>99.99%) pressure for the TurboVap II were maintained at 50°C and 8 psi, respectively. Final extracts in hexane were reduced to 1.0 ml and transferred to 2 ml glass vials sealed with Teflon-lined silicone rubber septa for GC analysis [21].

2.5.2 GC-ECD Analysis

F1 and F2 extracts (1 µl) were injected into a Varian 3400CX GC-ECD with an 8200 autosampler. Varian Star chromatography software (v4.01) was used to acquire and

analyze the chromatographic runs. A 30 m (L) x 0.25 mm (OD) fused silica capillary column coated with 0.25 µm DB-XLB was used to separate toxaphene components (Agilent/J&W Scientific, Folsom, CA). The GC oven was programmed as follows (hold times in parentheses): (i) 60°C (1 min); (ii) ramp to 120°C @ 10°C min^{-1}; (iii) ramp to 280°C @ 40°C /min (11 min). The total run time was 60 min. The injector and detector were maintained isothermal at 270°C and 330°C, respectively.

2.5.3 GC-ECNI-MS Analysis

To confirm the presence of individual toxaphene and other organochlorine analytes, extracts were analyzed on a Hewlett Packard 6890 Series II GC coupled to a 5973 mass selective detector operating in the electron capture negative ionization (ECNI) modes using an identical fused silica DB-XLB column as was used for GC-ECD analysis. The GC oven was programmed as follows (hold times in parentheses): (i) 60°C (1 min); (ii) ramp to 150°C @ 20°C min^{-1}; (iii) ramp to 280°C @ 4°C /min (2 min). The total run time was 40 min. The injector was programmed to track oven temperature. Helium at a constant flow rate of 1.0 ml/min was used as the carrier gas. Methane at a pressure of ~1 torr was used as the moderating gas. The quadrupole MS and ion source were maintained at 106 and 150°C, respectively. The MS was turned on after a 3.5 min solvent delay and was scanned between 200-500 daltons at 1.3 cycles s^{-1}. The electron multiplier was set to +400V bias for a total nominal voltage of ~1800V.

2.5.4 GC-EI-MS Analysis

To quantify the concentrations of PAH in our soil samples, extracts were analyzed on the HP6890II GC/5973 MSD operating in the electron ionization (EI) mode. The GC oven was programmed as follows (hold times in parentheses): (i) 60°C (1 min); (ii) ramp to 120°C @ 10°C min^{-1}; (iii) ramp to 300°C @ 4°C /min (8 min). The total run time was 60 min. The injector was programmed to track oven temperature. Helium at a constant flow rate of 1.0 ml/min was used as the carrier gas. The quadrupole MS and ion source were maintained at 150 and 230°C, respectively. The MS was turned on after a 5 min solvent delay ans was scanned between 50-550 daltons at ~1.5 cycles s^{-1}. The electron multiplier was set to +400V bias for a total nominal voltage of ~1650V.

2.5.5 Quantitation

Total toxaphene concentration (ΣTOX) was estimated by calibrating the GC-ECD with a technical toxaphene product standard ("TTX") provided by J. Hoffman of Hercules Inc and a toxaphene formulation purchased from Accustandard ("TTXA"). Serial dilutions of technical toxaphene were created in hexane at concentrations between 0.28 – 55 µg ml^{-1}. An average response factor for TTX was computed by summing the areas of all peaks of toxaphene, and dividing by the known standard mass. The TTX response was then applied to the summed area of peaks eluting within a specified retention time window (18-50 min) determined using the forced peak integration routine. For samples with detectable toxaphene residues in both F1 and F2 extracts using GC-ECNI-MS, ΣTOX was reported as the sum of both fractions. Areas for peaks corresponding to non-

toxaphene compounds eluting within this time window (e.g. Cl_4-Cl_7 PCBs in F1 extracts, and chlordanes and DDTs in F2 extracts) were subtracted from estimates of ΣTOX [21].

Total PCB and chlordane concentrations (ΣPCB and ΣChlordane, respectively) were estimated based on the sum of individual congeners in authentic standards. Seven congeners of chlordane were included in ΣChlordane estimates: heptachlor, oxychlordane, heptachlor epoxide, γ-chlordane, α-chlordane, trans- and cis-nonachlor. Fifteen penta- to decachlorinated PCB congeners (IUPAC nos 118, 188, 153, 105, 138, 187, 126, 128, 201, 180, 170, 195, 194, 206 and 209) in SRM2262 (NIST, Gaithersburg, MD) were summed to provide estimates of ΣPCB. Twenty four PAH congeners (SRM2260, NIST) ranging from naphthalene to benzo[ghi]perylene were summed for ΣPAH. Single point calibrations of the GC-ECNI-MS were used to estimate concentrations of chlordanes and PCBs. A 3 point calibration curve for PAHs was established using GC-EI-MS.

2.6 Quality Assurance/Quality Control

To ensure data of the highest quality, a comprehensive, performance based QA/QC plan was instituted and implemented for both ELISA and GC methods. These provisions included analysis of negative (blanks) and positive controls (matrix spikes), daily calibration of analytical instrumentation and the analysis of duplicate samples for precision. Unique project identifiers were assigned and sample jars/containers labeled with waterproof ink. When not in use, soil samples were kept cool ($\leq 4°C$) and in the dark.

2.6.1 ELISA

To verify the performance of each Toxaphene in Soil Test Kit, a positive and negative control were analyzed with each batch of 14 samples. The negative control consisted of methanol whereas the positive control consisted of methanol spiked with ~5 μg technical toxaphene dissolved in acetone. Preliminary attempts to analyze positive controls spiked with technical toxaphene in hexane resulted in unsatisfactory response. In addition, a reference soil sample from Skidaway Island (GA) and a spiked version of this soil were analyzed. Calibration of each test kit was performed using the 0.5, 2 and 10ppm calibrator standard solutions. Calibration curves were prepared for each test kit run. Exponential equations were fitted to the 3 calibration points using nonlinear regression. These equations were used to estimate ELISA-based toxaphene concentrations.

2.6.1.1 Positive Control

Positive controls consisting of Toxaphene in Soil Test Kit test tubes spiked with ~5 μg/ml TTX in methanol. All four positive controls prepared in this fashion exhibited concentrations in the correct (i.e. $2<x<10$ ppm) toxaphene concentration range (Table 4).

Table 4. ELISA results for positive control samples (TTX-spiked methanol).

Date	Absorption	conc. range [ppm]	conc. calc. [ppm]
4/17/2002, b	0.3344	2 < x < 10	7.04
4/18/2002, a	0.3386	2 < x < 10	6.49
4/18/2002, b	0.4807	2 < x < 10	6.44
5/14/2002, a	0.4667	2 < x < 10	3.21

2.6.1.2 Negative Control (Blank)

Negative controls consisting of pure methanol were required to confirm the correct use of the Test Kit. In practical terms, the presence of a dark yellow color corresponds to an absorption reading that is higher than the lowest calibrator solution (0.5 ppm). Consistently higher absorption for the 5 negative controls analyzed in this study indicates little or no interfering contamination was present (Table 5).

Table 5. Absorption for negative controls (NC) and 0.5 ppm calibrator solution.

Date	Absorption NC	Absorption 0.5ppm
4/13/02	1.3561	0.9835
4/15/02	1.5001	1.1053
4/17/02, a	1.1717	0.8415
4/17/02, b	1.4071	1.0156
5/14/02, a	1.1392	0.7876

2.6.1.3 Test Kit Calibration

Calibration of the spectrophotometer was performed in accordance with vendor instructions using 3 calibrator standard solutions -- 0.5, 2.0 and 10 ppm. As confirmed by vendor technical personnel, calibration curves were not linear (Fig. 13). Therefore, the test kit is only capable for semiquantitative concentration estimation. The absorption intensity may vary by kit but the nonlinear trend in each calibration curve is consistent. As a result, we performed nonlinear regression to generate exponential relationships between ELISA response and toxaphene concentration. These exponential equations were then used to estimate ELISA-based quantitative toxaphene concentrations.

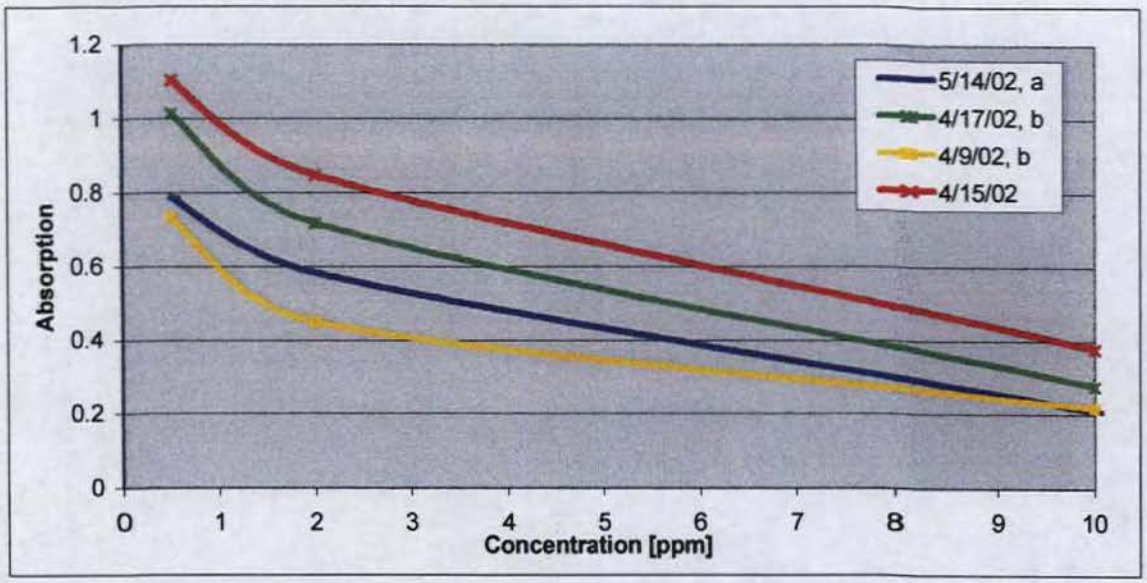


Figure 13. Nonlinear calibration curves for ELISA (Toxaphene in Soil Test Kit).

2.6.1.4 Spiked Reference Soil

Topsoil from a grass-covered field near SkIO on Skidaway Island (GA) was spiked with TTX dissolved in acetone or methanol. Nominal soil TTX concentrations after spiking were 0.1, 1 and 10 ppm. Spiked soils were allowed to age for 13h at room temperature prior to testing. Higher than expected ELISA responses and estimated concentrations were found (Table 6). In each case, the increasing trend in spiked toxaphene samples was detected by ELISA. The higher than expected concentrations could have been due to interfering contaminants present in Skidaway soil.

Table 6. ELISA results of spiked reference (Skidaway Island) soil.

Sample ID	Absorption	Spike [ppm]	conc. range [ppm]	conc. Calc. [ppm]
#1	0.7016	0.1	0.5 < x < 2	1.28
#2	0.5355	1.0	2 < x < 10	2.59
#3	0.2538	10.0	x > 10	10.22
#4	0.6582	0.1	0.5 < x < 2	1.57
#5	0.5015	1.0	2 < x < 10	2.95
#6	0.2312	10.0	x > 10	17.94

2.6.2 GAS CHROMATOGRAPHY

Calibration of the GC-ECD using solutions of TTX was highly linear ($R^2 > 0.99$), as was the calibration curve for PAH based on GC-EI-MS response. The recovery of technical toxaphene spiked into Skidaway reference soil was 95%. The mean recovery of recovery surrogates DBOFB and α-HCH was 66±22% (n=36).

2.6.2.1 BLANK

A procedural blank consisting of pre-extracted Hydromatrix and Ottawa sand was processed and analyzed for all target analytes with each batch of 15-20 soil samples. No target analyte was detected at greater than 10 ng/g (=ppb) in any blank.

2.6.2.2 GC CALIBRATION

The GC-ECD and GC-ECNI-MS were calibrated with serial dilutions of standards in hexane for the different compound classes: technical toxaphene (TTX) (Fig. 14); 22 component toxaphene congener mixture (TM2) (Fig. 15), 7 component chlordane mixture (SRM2261, PST A, B and C) (Fig. 16); 24 component PAH mixture (SRM2260) (Fig. 17), and a 28 component PCB mixture (SRM2262) that included the 15 congeners used to estimated ΣPCB. Because TTX contains several hundred individual components that are not resolved on a single GC column (Fig. 14), the GC-ECD calibration is based on the total mass of toxaphene as represented by the sum of peak areas in the ECD chromatogram (Fig. 18). The GC-ECD detection limit for technical toxaphene using this approach is ~0.01 μg/g.

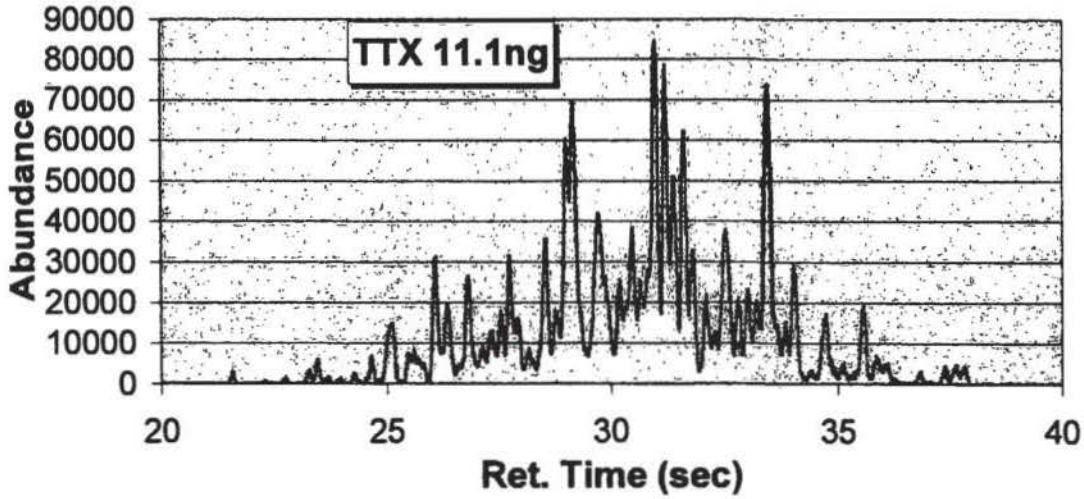


Figure 14. GC-ECNI-MS chromatogram of technical toxaphene.

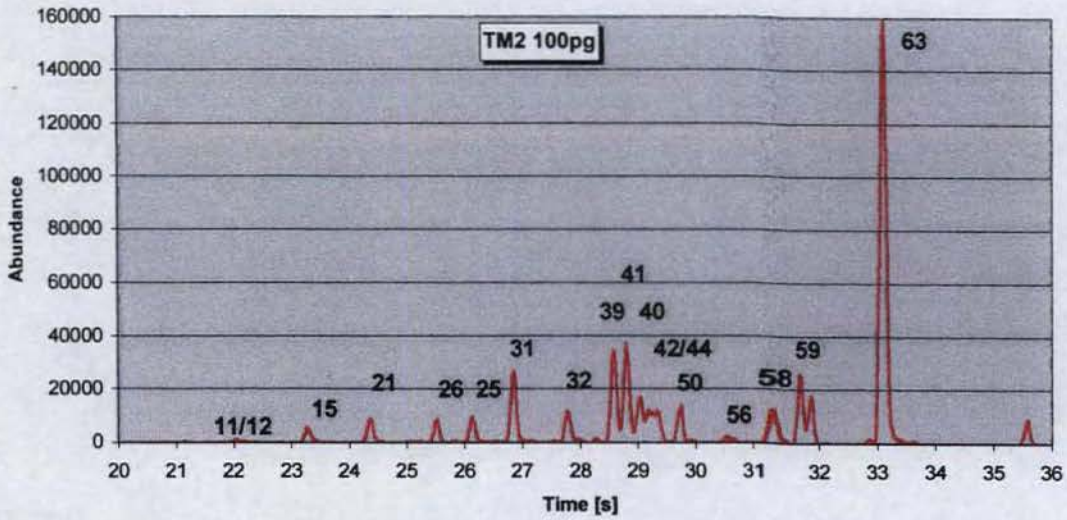


Figure 15. Twenty two component standard mixture of toxaphene congeners (100pg each congener, TM2, Dr. Ehrenstorfer, Augsburg, Germany). Peak numbers are defined by Dr. H. Parlar (TU Munich, Germany).

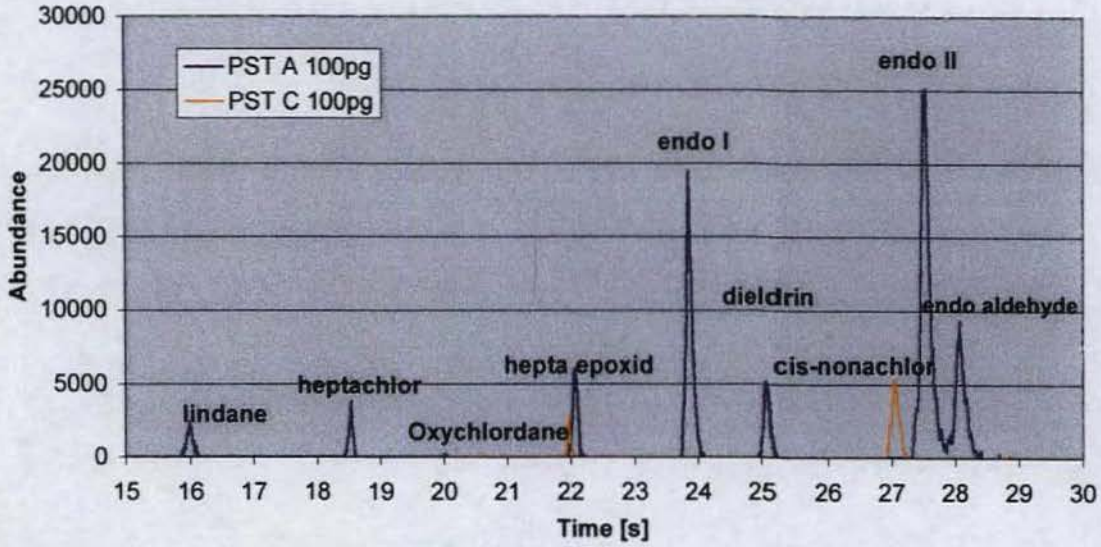


Figure 16. Custom organochlorine pesticide standard mixture containing 4 chlordane components (100pg each component; PST A and PST C).

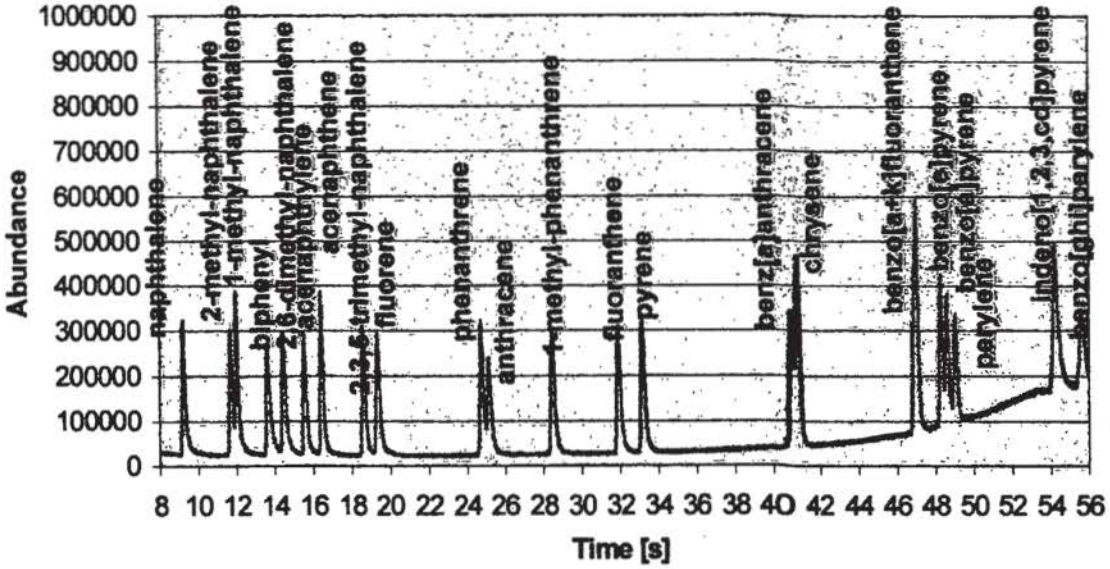


Figure 17. Twenty four component PAH standard mixture (1.9 ng each congener, SRM2260, NIST, Gaithersburg, MD).

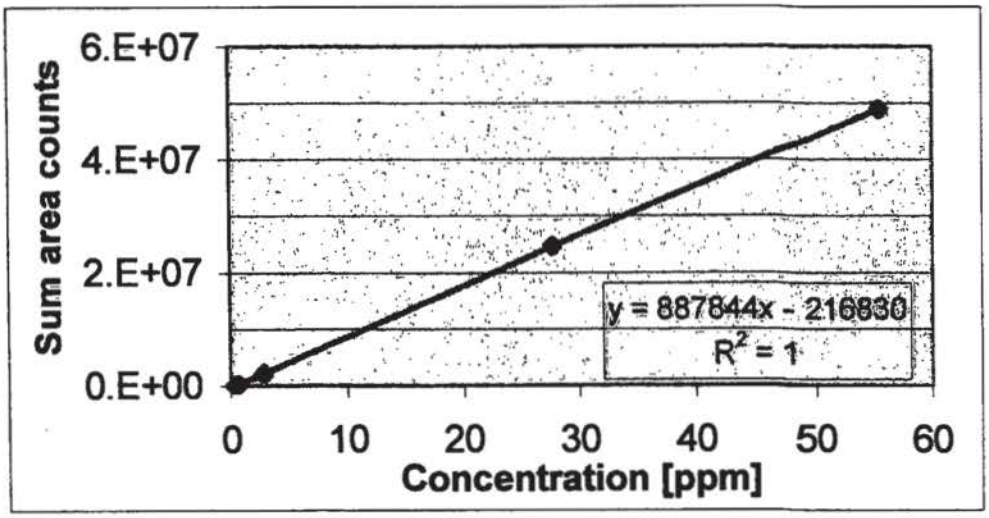


Figure 18. GC-ECD calibration curve based on technical toxaphene (TTX).

2.6.2.3 Spiked Reference Soil

The recovery of TTX spiked into Skidaway Island reference soil at ~5 µg/g was 95%. This sample was allowed to equilibrate for 16h at room temperature before it was processed and analyzed using the same protocols as was used for Brunswick soil samples.

2.7 Data and Statistical Analyses

All instrument calibration and sample concentration data were compiled and analyzed using Microsoft Excel 97 SR-1 spreadsheet software. Statistical evaluation of the data using analysis of variance (ANOVA) and t-tests were performed using the data analysis tool in Excel. GC and ELISA calibration curves were generated using the linear and nonlinear regression tools in Excel, respectively.

3. RESULTS

3.1 ELISA

3.1.1 GOODYEAR ELEMENTARY SCHOOL (GYES)

ELISA results by grid for GYES are summarized in Table 7 and shown in Fig. 6.

Table 7. ELISA results by sampling grid for Goodyear Elementary School soils.

Grid Number	Toxaphene Concentration Range (µg/g)
1	x < 0.5
2	x < 0.5
3	2 < x < 10
4	2 < x < 10
5	2 < x < 10
6	2 < x < 10
7	2 < x < 10
8 (rep. 1)	0.5 < x < 2
8 (rep. 2)	0.5 < x < 2
9	0.5 < x < 2
10	2 < x < 10
11-12 (rep. 1)	2 < x < 10
11-12 (rep. 2)	2 < x < 10
13	2 < x < 10
15	0.5 < x < 2
16 (rep. 1)	x > 10
16 (rep. 2)	x > 10
17	2 < x < 10
18-19	2 < x < 10
20-27	2 < x < 10
22 (rep. 1)	x < 0.5
22 (rep. 2)	0.5 < x < 2
23	2 < x < 10
23	0.5 < x < 2
24	2 < x < 10
25-26	2 < x < 10
29-30 (rep. 1)	x < 0.5
29-30 (rep. 2)	x < 0.5
35-28	2 < x < 10
36-37 (rep. 1)	x < 0.5
36-37 (rep. 2)	x < 0.5
38	0.5 < x < 2
39-40-41 (rep. 1)	x < 0.5
39-40-41 (rep. 2)	x < 0.5
42	2 < x < 10

3.1.2 RISLEY MIDDLE SCHOOL (RMS)

ELISA results by grid for RMS are summarized in Table 8 and shown in Fig. 8.

Table 8. ELISA results by sampling grid for Risley Middle soils.

Grid Number	Toxaphene Concentration Range (µg/g)
1	0.5 < x < 2
2	2 < x < 10
3-4	0.5 < x < 2
5	x < 0.5
6	2 < x < 10
7	x < 0.5
8	2 < x < 10
9	x < 0.5
10	2 < x < 10
11-21	0.5 < x < 2
15-25	0.5 < x < 2
16-26	x < 0.5
17 (rep. 1)	0.5 < x < 2
17 (rep. 2)	2 < x < 10
18	0.5 < x < 2
19	2 < x < 10
20	2 < x < 10
27 (rep. 1)	0.5 < x < 2
27 (rep. 2)	0.5 < x < 2
28	x < 0.5
28	0.5 < x < 2
29 (rep. 1)	x < 0.5
29 (rep. 2)	x < 0.5
30	0.5 < x < 2
31-32	0.5 < x < 2
33-34	0.5 < x < 2
35	2 < x < 10
36	0.5 < x < 2
37 (rep. 1)	0.5 < x < 2
37 (rep. 2)	0.5 < x < 2
38 (rep. 1)	0.5 < x < 2
38 (rep. 2)	0.5 < x < 2
39	0.5 < x < 2
40 (rep. 1)	0.5 < x < 2
40 (rep. 2)	0.5 < x < 2

3.1.3 BURROUGHS-MOLETTE ELEMENTARY SCHOOL (BMES)

ELISA results by grid for BMES are summarized in Table 9 and shown in Fig. 7.

Table 9. ELISA results by sampling grid for Burroughs-Molette Elementary School soils.

Grid Number	Toxaphene Concentration Range (µg/g)
1	x < 0.5
2	0.5 < x < 2
3	x < 0.5
4	x < 0.5
5	x < 0.5
6	x < 0.5
7	x < 0.5
8	x < 0.5
9	x < 0.5
10	x < 0.5
11 (rep. 1)	x < 0.5
11 (rep. 2)	0.5 < x < 2
12	x < 0.5
13	x < 0.5
14	x < 0.5
15 (rep. 1)	x < 0.5
15 (rep. 2)	x < 0.5
16	x < 0.5
17	x < 0.5
18	x < 0.5
19	x < 0.5
20	0.5 < x < 2
21	0.5 < x < 2
22	x < 0.5
23	x < 0.5
24	x < 0.5
25	0.5 < x < 2
26	x < 0.5
27	x < 0.5

3.1.4 EDO MILLER/LANIER FIELD, RECREATION AREA (EM/LF)

ELISA results by grid for EM/LF are summarized in Table 10 and shown in Fig. 9.

Table 10. ELISA results by sampling grid for Edo Miller/Lanier Field Recreational Area soils.

Grid Number	Toxaphene Concentration Range (µg/g)
1-1a-6a	0.5 < x < 2
2a-3a-4a	0.5 < x < 2
6-13-13a	0.5 < x < 2
7-14	0.5 < x < 2
11-18	x < 0.5
20-21	0.5 < x < 2
22-23	0.5 < x < 2
24-25	0.5 < x < 2
26-27	0.5 < x < 2
28-29	0.5 < x < 2
30-37-37a	0.5 < x < 2
35-36 (rep. 1)	x < 0.5
35-36 (rep. 2)	x < 0.5

3.1.5 SUMMARY

Based on ELISA results, soils from Goodyear ES contained the most toxaphene (Table 11, Fig. 19). More than 50% of samples from GYES were classified in the moderately contaminated (2.0<x<10 ppm) range. A single sample (GYES16) was classified in the highly contaminated (x>10 ppm) range. Soils from Risley MS ranked second, with 25% classified as moderately contaminated. In contrast, soils from Burroughs-Molette ES and Edo Miller/Lanier Field Recreational Area were similarly low in organochlorine contamination, with greater than 80% classified as having low concentrations (0.5>x >2.0 ppm) and the remainder having undetectable (x<0.5 ppm) levels. In cases where duplicate ELISA data indicated different toxaphene concentration ranges for the same soil sample, the sample was placed in the higher concentration range (Tables 7-10).

Table 11. Classification and sample percentages of toxaphene concentration ranges in study site soils.

Access areas	x < 0.5 [ppm]	0.5 < x < 2 [ppm]	2 < x < 10 [ppm]	x > 10 [ppm]
Burrough-Molette ES	14.8%	85.2%	0.0%	0.0%
Goodyear ES	22.2%	18.5%	55.6%	3.7%
Risley Middle School	21.4%	53.6%	25.0%	0.0%
Edo Miller/Lanier Field RA	16.7%	83.3%	0.0%	0.0%

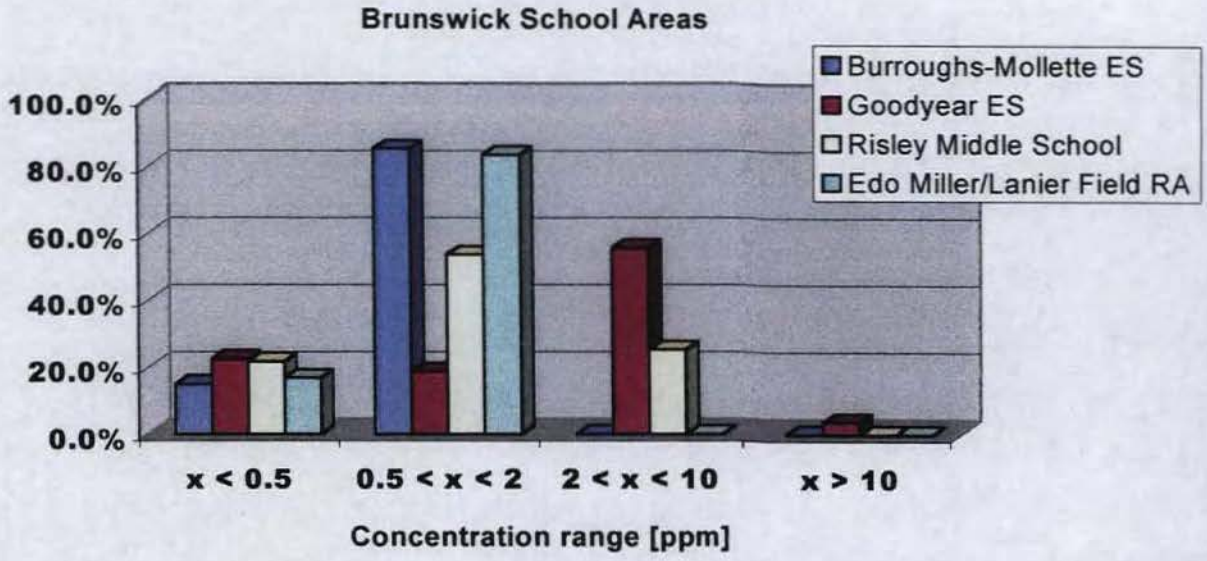


Figure 19. Percent distribution of ELISA toxaphene concentration ranges.

3.2 Gas Chromatography

3.2.1 Trace Organic Contaminant Concentrations

Total toxaphene (ΣTOX) concentrations in the 36 samples analyzed by GC ranged from <0.01 to 0.38 μg/g (Table 12). Ten of 36 (28%) samples had detectable levels of toxaphene, with a mean ΣTOX of 0.11±0.11 μg/g. In contrast, all 36 samples had detectable levels of PAH and chlordane, and 35 of 36 had detectable levels of PCBs. The mean Σchlordane (31.3±128 ng/g) was roughly 2-fold higher than the mean ΣPCB (14±13 ng/g). More importantly, mean Σchlordane exceeded the ELISA MDL (17.9 ng/g, Table 3). Soil from Goodyear ES grid no. 16 ("GY16") contained 795 ng/g chlordane, a level that was 10-fold higher than the next highest chlordane concentration (GY18-19). The maximum ΣPCB was 63.9 ng/g (EMF1-1a-6a). Mean ΣPAH was the highest of the 4 trace organic classes reported herein (1.19±3.79 μg/g) with a single sample (GY10) containing 3 times as much as the next highest sample. Interestingly, the mean toxaphene concentration as predicted by ELISA nonlinear concentration-response curves (1.4±1.4 μg/g) was more than 10-fold higher than that estimated by GC.

3.2.2 Toxaphene Concentrations and Congener Distributions

Detailed toxaphene congener analyses were not performed as part of this study. However, GC-ECNI-MS analysis of the soil sample with the highest ΣTOX (EMF7-14) revealed that Cl_8 bornanes in the 22-component TM2 standard mixture (Parlar nos. 41, 40, 42 and 44; Fig. 15) were prominent. Of the samples containing detectable levels of toxaphene, roughly 50% were from EM/LF and the remainder from BMES. Interestingly, none of the samples from GYES had detectable levels of toxaphene (Fig. 20).

Table 12. ELISA and GC-based concentrations of toxaphene and other trace organic contaminants. [1]

Sample	ELISA conc. range [µg/g]	ELISA conc. calc.[2] [µg/g]	Σ PAH [µg/g]	Σ PCB [ng/g]	ΣChlordane [ng/g]	ΣToxaphene [µg/g]
GY39-41	x < 0.5	-0.5	0.23	0.14	1.31	<0.01
BM17	x < 0.5	-0.3	0.01	3.04	0.19	0.02
BM24	x < 0.5	-0.2	0.01	23.20	1.80	0.03
BM26	x < 0.5	-0.2	<0.01	33.94	2.20	0.03
BM13	x < 0.5	-0.2	0.64	0.00	1.55	<0.01
EMF11-18	x < 0.5	-0.1	<0.01	12.96	3.85	<0.01
GY36-37	x < 0.5	0.0	0.84	26.65	2.15	<0.01
BM4	x < 0.5	0.1	0.07	6.37	0.16	<0.01
RIS7	x < 0.5	0.4	0.12	11.43	0.69	0.03
BM25	0.5 < x < 2	0.5	0.02	17.37	1.15	<0.01
BM21	0.5 < x < 2	0.6	0.01	11.47	0.94	<0.01
BM2	0.5 < x < 2	0.6	0.17	32.47	1.32	<0.01
RIS40	0.5 < x < 2	0.8	0.12	3.36	0.39	<0.01
EMF24-25 (Rep.1)	0.5 < x < 2	0.8	<0.01	2.80	5.66	<0.01
EMF1-1a-6a	0.5 < x < 2	0.8	0.21	63.91	14.47	0.19
EMF24-25 (Rep. 2)	0.5 < x < 2	0.8	<0.01	1.44	4.75	<0.01
EMF28-29	0.5 < x < 2	0.8	0.01	31.15	1.53	<0.01
EMF22-23	0.5 < x < 2	1.0	0.01	32.38	10.50	0.07
BM20 (Rep.1)	0.5 < x < 2	1.1	0.02	12.80	7.46	0.19
BM20 (Rep.2)	0.5 < x < 2	1.1	0.02	12.80	3.10	0.17
EMF30-37	0.5 < x < 2	1.4	0.08	20.50	9.64	0.04
GY23	0.5 < x < 2	1.4	0.24	2.38	10.38	<0.01
RIS31-32	0.5 < x < 2	1.4	2.49	16.21	4.60	<0.01
EMF2a-3a-4a	0.5 < x < 2	1.4	0.02	5.38	11.54	0.05
EMF7-14	0.5 < x < 2	1.9	0.01	19.93	54.88	0.38
RIS35	2 < x < 10	2.1	7.30	18.16	9.34	<0.01
GY3	2 < x < 10	2.1	0.15	0.82	10.17	<0.01
RIS6	2 < x < 10	2.2	0.72	12.74	2.54	<0.01
GY6	2 < x < 10	2.2	0.07	18.54	0.74	<0.01
RIS10	2 < x < 10	2.9	0.05	13.98	5.06	<0.01
GY24	2 < x < 10	3.0	0.59	1.32	22.72	<0.01
GY23	2 < x < 10	3.6	0.24	2.38	10.38	<0.01
GY18-19	2 < x < 10	3.9	1.20	1.03	78.72	<0.01
RIS2	2 < x < 10	4.0	0.61	18.10	1.99	<0.01
GY10	2 < x < 10	4.0	21.68	2.19	19.95	<0.01
GY20-27	2 < x < 10	4.9	1.80	2.78	45.75	<0.01
GY16 (Rep.1)	x > 10	10.0	0.25	0.37	794.66	<0.01
GY16 (Rep.2)	x > 10	10.0	0.34			<0.01

1 Ranked in ascending order of toxaphene concentration as determined by ELISA.

2 Calculated ELISA toxaphene concentration based on model equations of the form: $y=y_0+a*\exp(-b*x)$.

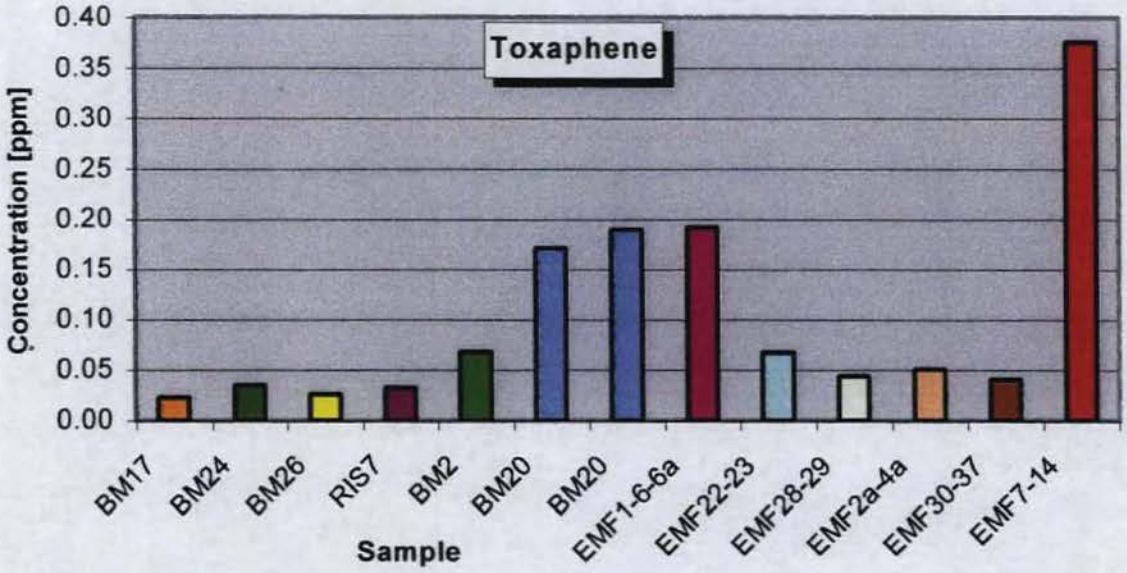


Figure 20. GC-based ΣTOX estimates (μg/g) in Brunswick public access area soils.

3.2.3 Chlordane Concentrations and Congener Distributions

Chlordane concentrations were highest in GYES soils, followed by soils from EM/LF. In fact, the 11 highest ranked samples in terms of Σchlordane were from these 2 areas (Fig. 21). Congener distributions were dominated by 3 compounds -- γ- and α-chlordane and *trans*-nonachlor (see also Appendix A). The dominance of γ- and α-chlordane is clear in GC-ECNI-MS confirmatory chromatograms (Fig. 22).

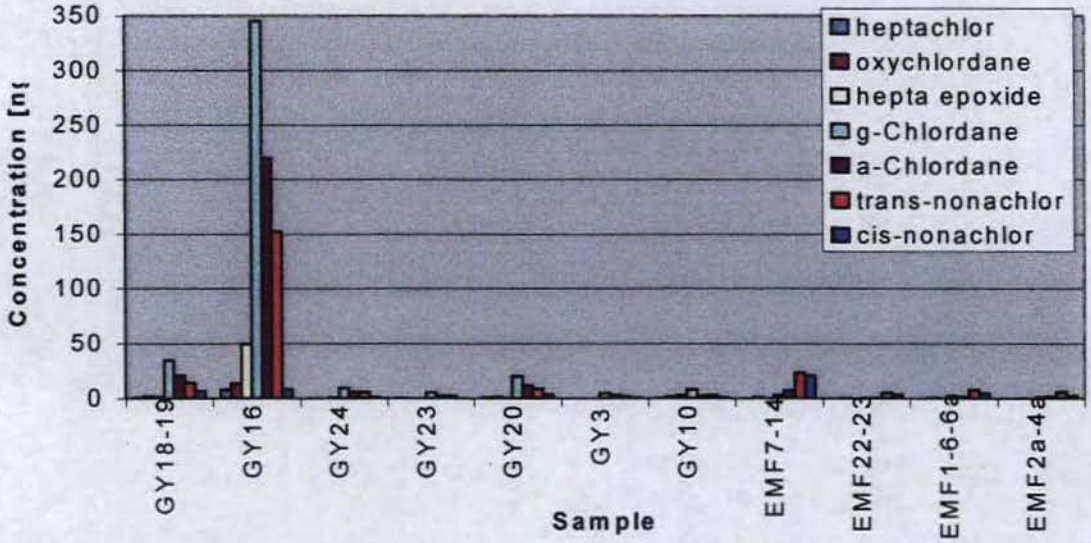


Figure 21. Chlordane concentration by component for the 11 soil samples with the highest Σchlordane (i.e. > 10 ng/g).

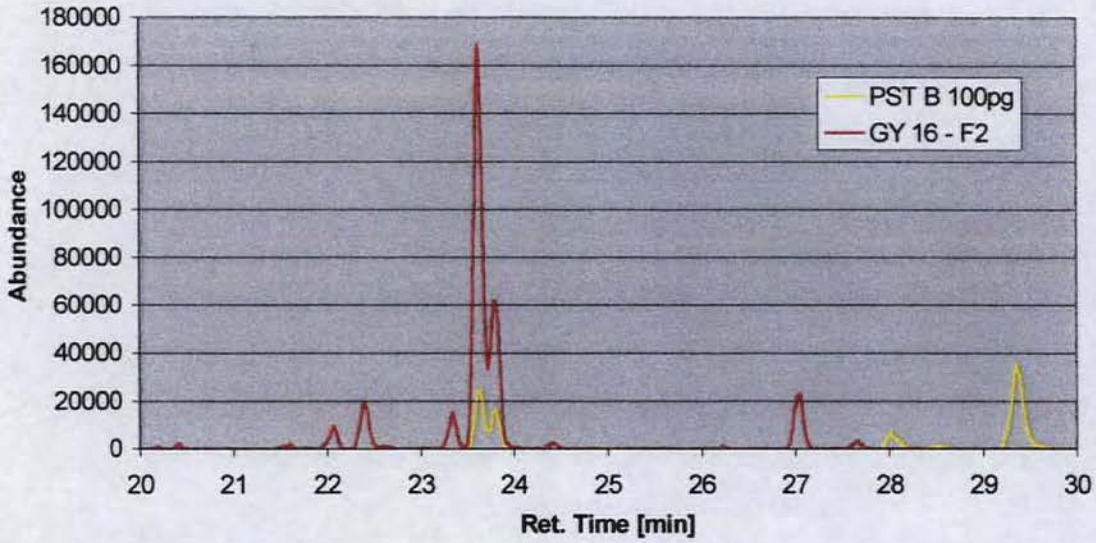


Figure 22. GC-ECNI-MS chromatogram of GY16 soil overlain by a pesticide standard mixture containing γ- and α-chlordane, eluting between 23 and 24 min.

3.2.4 PAH Concentrations and Congener Distributions

PAH concentrations were highest in GYES soils, followed by soils from Risley MS. The highest sample (GY10, 21.7 μg/g) was 3-fold higher than the next highest sample (RMS35, 7.30 μg/g). High molecular weight PAH, i.e. those with 4 or more fused rings, dominated the congener distribution in the majority of samples with the 4 ring isomers fluoranthene and pyrene having the greatest abundance (Fig. 23). The predominance of high MW PAH is consistent with PAH "soot", originating from sources such as combustion engine exhaust and/or highly weathered petroleum.

3.2.5 PCB Concentrations and Congener Distributions

PCB concentrations were highest in EM/LF and BMES soils. GC-ECNI-MS analysis of EMF1-6-6a confirms the presence of highly chlorinated congeners (e.g. IUPAC nos. 118, 153, 105, 138, 187, 180, 194, 206 and 209 (Fig. 24). The dominance of PCB-138, a hexachlorinated congener, suggests that a technical mixture with ~50% chlorine (e.g. Aroclor 1248 or 1254) is the primary source of soil-associated PCBs. Detection of PCB-206 and -209 also indicates the presence of Aroclor 1268 throughout the area (Fig. 25).

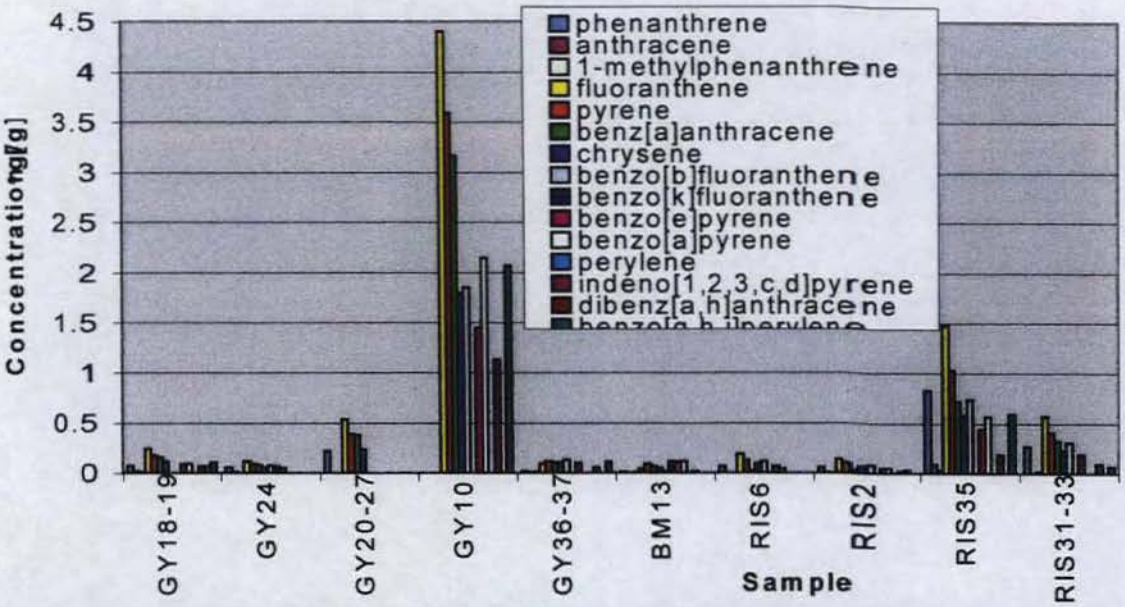


Figure 23. PAH congener concentrations and distributions for soil samples with ΣPAH > 0.5 µg/g.

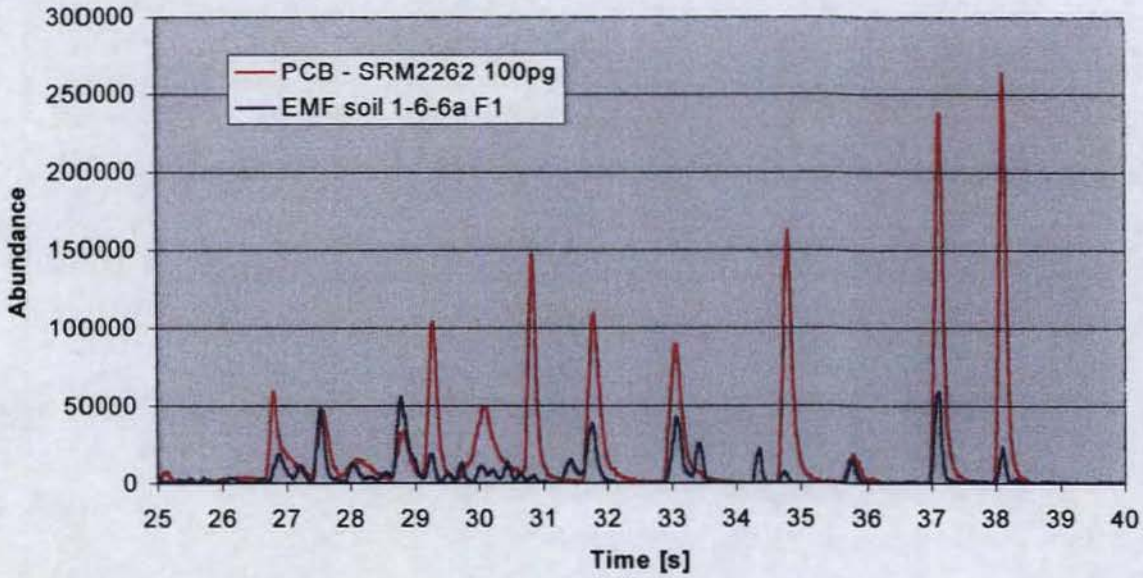


Figure 24. GC-ECNI-MS chromatogram of soil sample EMF1-6-6a overlain with that of a PCB congener standard mixture (SRM2262, NIST).

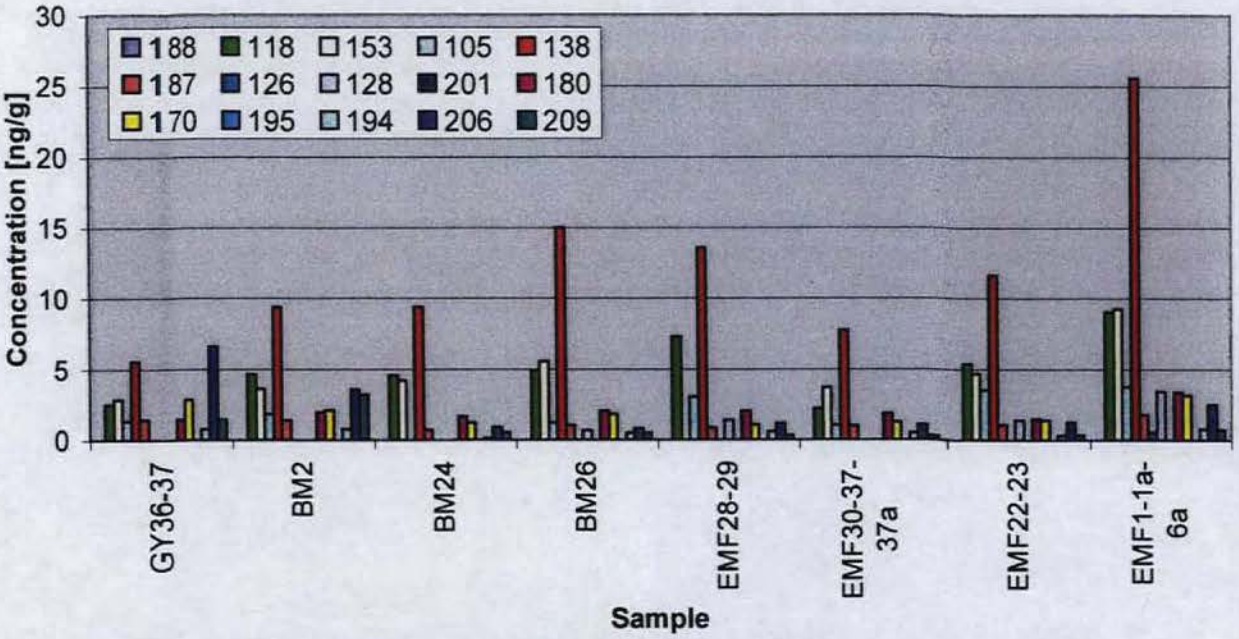


Figure 25. PCB congener concentrations and distributions for soil samples with ΣPCB > 20 ng/g.

3.3 Linear Regression – ELISA vs. GC Results

Linear regression analyses were performed to investigate relationships between soil toxaphene concentrations as predicted by ELISA ("ELISA-TOX") and the total concentrations of the 4 classes of organic contaminants as measured by GC. ΣChlordane was strongly correlated with ELISA-TOX, accounting for 57% of the total variation in this relationship (Table 13; R^2=0.57; p<<0.001). Based on a smaller sample size (n=10), the association between GC- and ELISA-based ΣTOX was also significant (R^2=0.47; p<0.5). Neither ΣPAH nor ΣPCB were significantly correlated with ELISA results.

Table 13. Strength of correlation between ELISA-TOX and GC-based estimates of ΣTOX, Σchlordane, ΣPAH and ΣPCB.

Relationship	N	R Square	P value
ELISA-TOX. vs. ΣChlordane	35	0.5742	8.7E-08
ELISA-TOX. vs. ΣToxaphene	10	0.4716	0.0196
ELISA-TOX. vs. ΣPCB	35	0.0903	0.0750
ELISA-TOX. vs. ΣPAH	36	0.0323	0.2870

4. SUMMARY AND CONCLUSIONS

Of the 94 surface soil samples collected and analyzed for toxaphene residues by ELISA, a single sample from Goodyear ES ("GY16") was classified as highly contaminated (> 10 ppm). Toxaphene residues were not detected in this sample using GC-ECD and GC-ECNI-MS, which did indicate that chlordanes were by far the predominant class of organochlorine contaminants. Furthermore, the estimated concentration of chlordane-related compounds in this sample (795 ng/g) far exceeded the interference threshold (17.9 ng/g) as published by the ELISA kit manufacturer. Of the 36 samples analyzed by GC, 75% (27 of 36) were classified by ELISA as containing detectable levels of toxaphene (> 0.5 ppm) and 33% (12 of 36) classified as containing greater than 2 ppm. However, GC analyses indicated only 27% (10 of 36) of these samples contained detectable levels of toxaphene residues (> 0.01 μg/g) and none contained greater than 0.5 ppm.

Other classes of organic contaminants were present, including PAHs and PCBs, with isolated samples containing relatively high levels (>1 ppm). Correlational analyses between ELISA-based ΣTOX and the GC-determined concentrations of toxaphene, PAH, PCB and chlordane indicated, however, that chlordane concentrations best explained the trend in ELISA results. Although ELISA and GC-based estimates of toxaphene residue concentrations were significantly correlated, the difference in the magnitude of ELISA-based toxaphene levels was 10-fold or higher. Thus, we conclude that chlordane, and possibly other unknown/uncharacterized substances in the soil interfered with the ELISA Test Kit, resulting in erroneously high predictions of toxaphene contamination.

The maximum GC-based ΣTOX of 0.38 ppm also suggests little or no risk due to toxaphene residues in surface (0-3 inches) soils from these public access areas. Human health risks associated with topsoils in areas with elevated trace organic contamination should be evaluated on a case-by-case basis. This may include areas represented by grids no. 16 (Σchlordane = 795 ppb) and 10 (ΣPAH = 22 ppm) at Goodyear ES.

Although not measured in this study, soil moisture, texture and composition (i.e. percent water, grain size and total organic carbon) is known to greatly influence the ability of a soil to retain (hydrophobic) organic contaminants such as toxaphene. Clearly, "soils" of large mean grain size and low TOC/water content, such as the hard-packed sands found at many locations during the study, have low potential for retaining environmentally relevant levels of the target analytes. In future studies, prioritization for testing soil contamination should be given to areas with fine-grained, high TOC soils.

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7. APPENDIX A

7.1 PAH Congener GC Concentrations (µg/g)

Sample ID Congener	GY18-19 Csamp [ppm]	GY16 Rep. 1 [ppm]	GY16 Rep. 2 [ppm]	GY24 Csamp [ppm]	GY23 Csamp [ppm]	GY20-27 Csamp [ppm]	GY3 Csamp [ppm]	GY39-41 Csamp [ppm]	GY6 Csamp [ppm]
naphthalene	nd	nd	nd	nd	nd	nd	nd	nd	nd
2-methylnaphthalene	nd	nd	nd	nd	nd	0.010	nd	nd	nd
1-methylnaphthalene	nd	nd	nd	nd	nd	0.0049	nd	nd	nd
biphenyl	nd	nd	nd	0.0005	nd	nd	nd	nd	nd
2,6-dimethylnaphthalene	nd	nd	nd	nd	nd	nd	nd	nd	nd
acenaphthylene	nd	nd	nd	nd	nd	nd	nd	nd	nd
acenaphthene	nd	nd	nd	0.0024	nd	0.0071	nd	nd	nd
2,3,5-trimethylnaphthalene*	nd	nd	nd	nd	nd	nd	nd	nd	nd
fluorene	nd	nd	nd	0.0019	nd	0.0087	nd	nd	nd
phenanthrene	0.072	0.0078	0.040	0.056	0.020	0.22	0.0092	0.016	nd
anthracene	0.013	nd	0.0021	0.0089	0.0010	nd	nd	0.0025	nd
1-methylphenanthrene	0.0091	nd	0.024	nd	nd	nd	nd	0.0024	nd
fluoranthene	0.24	0.037	0.093	0.12	0.053	0.54	0.032	0.046	0.011
pyrene	0.172	0.023	0.059	0.089	0.037	0.39	0.024	0.043	0.011
benz[a]anthracene	0.16	0.052	0.048	0.078	0.035	0.38	0.022	0.039	0.0074
chrysene	0.12	0.040	0.039	0.052	0.027	0.24	nd	0.028	0.012
benzo[b]fluoranthene	nd	0.030	nd	0.075	0.016	nd	0.024	0.048	0.015
benzo[k]fluoranthene	nd	0.026	nd	0.065	0.021	nd	0.021	nd	nd
benzo[e]pyrene	0.086	0.017	0.031	0.046	0.026	nd	0.015	nd	0.010
benzo[a]pyrene	0.096	nd	nd	nd	nd	nd	nd	nd	nd
perylene	nd	nd	nd	nd	nd	nd	nd	nd	nd
indeno[1,2,3,c,d]pyrene	0.064	0.0090	nd	nd	nd	nd	nd	nd	0.0048
dibenz[a,h]anthracene	0.063	nd	nd	nd	nd	nd	nd	nd	nd
benzo[g,h,i]perylene	0.11	0.011	nd	nd	nd	nd	nd	nd	0.0026
Σ PAH	1.2	0.25	0.34	0.59	0.24	1.8	0.15	0.23	0.074

Sample ID Congener	GY10 Csamp [ppm]	GY36-37 Csamp [ppm]	BM20 Rep. 1 [ppm]	BM20 Rep. 2 [ppm]	BM2 Csamp [ppm]	BM4 Csamp [ppm]	BM13 Csamp [ppm]	BM17 Csamp [ppm]	BM21 Csamp [ppm]
naphthalene	nd	nd	nd	nd	nd	nd	nd	nd	nd
2-methylnaphthalene	nd	nd	nd	nd	nd	nd	nd	nd	nd
1-methylnaphthalene	nd	nd	nd	nd	nd	nd	nd	nd	nd
biphenyl	nd	nd	nd	nd	nd	nd	nd	nd	nd
2,6-dimethylnaphthalene	nd	nd	nd	nd	nd	nd	nd	nd	nd
acenaphthylene	nd	nd	nd	nd	nd	nd	nd	nd	nd
acenaphthene	nd	nd	nd	nd	nd	nd	nd	nd	nd
2,3,5-trimethylnaphthalene*	nd	nd	nd	nd	nd	nd	nd	nd	nd
fluorene	0.075	nd	nd	nd	nd	nd	nd	nd	nd
anthracene	nd	0.002	nd	nd	nd	nd	nd	nd	nd
1-methylphenanthrene	nd	0.007	nd	nd	nd	nd	0.004	nd	nd
fluoranthene	4.4	0.094	0.003	0.001	0.031	0.019	0.044	0.002	0.004
pyrene	3.6	0.12	0.002	0.005	0.035	0.015	0.096	0.002	nd
benz[a]anthracene	3.2	0.10	nd	nd	nd	0.005	0.067	nd	nd
chrysene	1.8	0.10	0.001	0.002	0.016	0.009	0.047	0.001	0.001
benzo[b]fluoranthene	1.8	0.13	0.003	0.005	0.051	0.006	0.006	0.007	0.003
benzo[k]fluoranthene	nd	nd	0.003	nd	nd	0.007	0.12	nd	0.004
benzo[e]pyrene	1.4	0.099	0.003	0.003	0.033	0.012	0.11	nd	nd
benzo[a]pyrene	2.1	nd	nd	0.001	nd	nd	0.12	nd	nd
perylene	nd	nd	nd	nd	nd	nd	nd	nd	nd
indeno[1,2,3,c,d]pyrene	1.1	0.055	nd	nd	nd	nd	0.016	nd	nd
dibenz[a,h]anthracene	nd	nd	nd	nd	nd	nd	nd	nd	nd
benzo[g,h,i]perylene	2.1	0.11	0.002	nd	nd	nd	nd	nd	nd
Σ PAH	22	0.84	0.018	0.017	0.17	0.072	0.64	0.012	0.012

Sample ID Congener	BM24 Csamp [ppm]	BM26 Csamp [ppm]	BM25 Csamp [ppm]	RIS10 Csamp [ppm]	RIS6 Csamp [ppm]	RIS2 Csamp [ppm]	RIS7 Csamp [ppm]	RIS35 Csamp [ppm]	RIS40 Csamp [ppm]	RIS31-33 Csamp [ppm]
naphthalene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
2-methylnaphthalene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
1-methylnaphthalene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
biphenyl	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
2,6-dimethylnaphthalene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
acenaphthylene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
acenaphthene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
2,3,5-trimethylnaphthalene*	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
fluorene	nd	nd	nd	nd	0.001	nd	nd	nd	nd	nd
phenanthrene	nd	nd	nd	0.013	0.063	0.051	0.005	0.83	0.012	0.27
anthracene	nd	nd	nd	nd	nd	0.004	nd	0.093	nd	nd
1-methylphenanthrene	nd	nd	nd	nd	nd	0.001	0.004	0.032	0.002	0.018
fluoranthene	0.002	0.004	0.015	0.015	0.19	0.14	0.030	1.48	0.031	0.58
pyrene	0.003	nd	0.004	0.021	0.13	0.10	0.024	1.031	0.028	0.41
benz[a]anthracene	nd	nd	nd	nd	0.022	0.028	0.009	0.72	0.008	0.33
chrysene	nd	0.001	0.003	nd	0.092	0.069	0.019	0.58	0.013	0.23
benzo[b]fluoranthene	0.001	nd	0.003	nd	0.12	0.081	0.010	0.74	0.009	0.31
benzo[k]fluoranthene	nd	nd	nd	nd	nd	nd	0.008	nd	0.008	nd
benzo[e]pyrene	nd	nd	nd	nd	0.065	0.047	0.012	0.44	0.006	0.19
benzo[a]pyrene	nd	nd	nd	nd	0.045	0.045	nd	0.57	nd	nd
perylene	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
indeno[1,2,3,c,d]pyrene	nd	nd	nd	nd	nd	0.017	nd	0.19	nd	0.092
dibenz[a,h]anthracene	nd	nd	nd	nd	nd	0.030	nd	nd	nd	nd
benzo[g,h,i]perylene	nd	nd	nd	nd	nd	nd	nd	0.60	nd	0.067
Σ PAH	0.006	0.005	0.024	0.049	0.72	0.61	0.12	7.3	0.12	2.5

Sample ID Congener	EMF28-29 Csamp [ppm]	EMF30-37-37a Csamp [ppm]	EMF7-14 Csamp [ppm]	EMF11-18 Csamp [ppm]	EMF22-23 Csamp [ppm]	EMF1-1a-6a Csamp [ppm]	EMF2a-3a-4a Csamp [ppm]	EMF24-25 Csamp [ppm]
naphthalene	nd	nd	nd	nd	nd	nd	nd	nd
2-methylnaphthalene	nd	nd	nd	nd	nd	nd	nd	nd
1-methylnaphthalene	nd	nd	nd	nd	nd	nd	nd	nd
biphenyl	nd	nd	nd	nd	nd	nd	nd	nd
2,6-dimethylnaphthalene	nd	nd	nd	nd	nd	nd	nd	nd
acenaphthylene	nd	nd	nd	nd	nd	nd	nd	nd
acenaphthene	nd	nd	nd	nd	nd	nd	nd	nd
2,3,5-trimethylnaphthalene*	nd	nd	nd	nd	nd	nd	nd	nd
fluorene	nd	nd	nd	nd	nd	nd	nd	nd
phenanthrene	nd	nd	nd	nd	nd	nd	nd	nd
anthracene	nd	nd	nd	0.001	nd	0.002	nd	nd
1-methylphenanthrene	0.002	nd	nd	nd	nd	0.001	nd	nd
fluoranthene	0.003	nd	0.006	nd	0.003	0.059	0.016	nd
pyrene	0.004	0.015	nd	nd	0.007	0.052	0.003	nd
benz[a]anthracene	nd	nd	nd	nd	nd	0.022	nd	nd
chrysene	nd	0.017	0.001	0.002	0.001	0.010	0.001	nd
benzo[b]fluoranthene	nd	0.051	nd	nd	nd	0.043	0.002	nd
benzo[k]fluoranthene	nd	nd	nd	nd	nd	nd	nd	nd
benzo[e]pyrene	nd	nd	nd	nd	nd	0.009	nd	nd
benzo[a]pyrene	nd	nd	nd	nd	nd	nd	0.001	nd
perylene	nd	nd	nd	nd	nd	nd	nd	nd
indeno[1,2,3,c,d]pyrene	nd	0.001	nd	nd	nd	0.007	nd	nd
dibenz[a,h]anthracene	nd	nd	nd	nd	nd	nd	nd	nd
benzo[g,h,i]perylene	nd	nd	nd	nd	nd	0.003	nd	nd
Σ PAH	0.009	0.084	0.007	0.003	0.011	0.21	0.024	<0.001

7.2 PCB Congener GC Concentrations (ng/g)

Sample ID Congener	GY18-19 Csamp [ppb]	GY16 Rep. 1 [ppb]	GY16 Rep. 2 [ppb]	GY24 Csamp [ppb]	GY23 Csamp [ppb]	GY20-27 Csamp [ppb]	GY3 Csamp [ppb]	GY39-41 Csamp [ppb]	GY6 Csamp [ppb]	GY10 Csamp [ppb]	GY36-37 Csamp [ppb]
188	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
118	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	2.5
153	nd	nd	nd	0.034	0.081	0.27	nd	nd	0.81	nd	2.8
105	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	1.3
138	nd	nd	nd	0.035	nd	nd	nd	nd	1.1	nd	5.6
187	nd	nd	nd	nd	0.083	0.31	nd	nd	1.5	0.084	1.4
126	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
128	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
201	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.19	nd
180	nd	nd	nd	nd	nd	nd	nd	nd	1.1	nd	1.4
170	nd	0.045	nd	0.39	0.50	0.68	0.084	nd	3.1	0.42	2.9
195	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
194	nd	nd	nd	nd	nd	nd	nd	nd	0.85	nd	0.74
206	0.69	0.32	nd	0.51	1.4	0.86	0.65	0.14	7.8	1.2	6.6

Sample ID Congener	BM20 Rep. 1 [ppb]	BM20 Rep. 2 [ppb]	BM2 Csamp [ppb]	BM4 Csamp [ppb]	BM13 Csamp [ppb]	BM17 Csamp [ppb]	BM21 Csamp [ppb]	BM24 Csamp [ppb]	BM26 Csamp [ppb]	BM25 Csamp [ppb]	RIS10 Csamp [ppb]
188	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
118	nd	nd	4.7	0.30	nd	nd	1.8	4.6	4.9	1.3	nd
153	2.3	nd	3.6	0.90	nd	0.39	2.0	4.2	5.6	3.5	0.71
105	nd	nd	1.8	nd	nd	nd	nd	nd	1.2	nd	nd
138	6.0	nd	9.4	0.87	nd	0.88	4.9	9.4	15	8.4	0.82
187	0.59	nd	1.4	0.27	nd	0.11	0.30	0.71	1.0	0.57	1.0
126	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
128	nd	nd	nd	nd	nd	nd	0.31	nd	0.66	nd	nd
201	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
180	1.1	nd	1.9	0.50	nd	0.14	0.74	1.7	2.0	1.5	0.74
170	nd	nd	2.1	0.38	nd	0.071	0.45	1.2	1.8	0.54	1.4
195	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
194	0.19	nd	0.76	nd	nd	0.097	nd	0.11	0.46	0.26	0.81
206	1.3	nd	3.6	1.5	nd	0.83	0.68	0.87	0.78	0.75	6.3
209	1.314	nd	3.2	1.7	nd	0.52	0.34	0.50	0.48	0.57	2.2
Σ PCB	13	<0.001	32	6.4	<0.001	3.0	11	23	34	17	14

Sample ID Congener	RIS6 Csamp [ppb]	RIS2 Csamp [ppb]	RIS7 Csamp [ppb]	RIS35 Csamp [ppb]	RIS40 Csamp [ppb]	RIS31-33 Csamp [ppb]	EMF28-29 Csamp [ppb]	EMF30-37-37a Csamp [ppb]	EMF7-14 Csamp [ppb]	EMF11-18 Csamp [ppb]
188	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
118	0.91	3.3	nd	nd	nd	0.35	7.2	2.2	0.93	2.1
153	1.8	2.6	0.29	1.1	nd	1.3	nd	3.7	3.7	1.8
105	nd	nd	nd	nd	nd	nd	3.0	1.0	nd	0.58
138	3.4	7.0	0.55	0.87	nd	3.1	14	7.7	8.6	3.6
187	0.69	0.74	1.0	1.5	0.26	1.3	0.81	0.96	1.1	0.66
126	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
128	nd	nd	nd	nd	nd	nd	1.4	nd	0.63	nd
201	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
180	0.75	0.88	0.26	1.3	nd	1.1	2.1	1.9	1.6	1.0
170	1.4	1.4	1.4	3.0	0.31	2.4	1.0	1.2	1.7	0.92
195	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
194	0.38	nd	0.40	1.0	nd	1.0	0.58	0.50	0.34	0.26
206	2.7	1.8	5.6	7.2	2.3	5.2	1.1	1.1	1.3	1.6
209	0.67	0.38	1.8	2.2	0.45	0.44	0.28	0.28	0.21	0.41
Σ PCB	13	18	11	18.	3.4	16	31	20.	20	13

Sample ID Congener	EMF22-23 Csamp [ppb]	EMF1-1a-6a Csamp [ppb]	EMF2a-3a-4a Csamp [ppb]	EMF24-25 Rep. 1 [ppb]	EMF24-25 Rep. 2 [ppb]
188	nd	nd	nd	nd	nd
118	5.4	9.0	0.48	nd	nd
153	4.7	9.2	0.94	0.11	0.41
105	3.5	3.8	nd	nd	nd
138	12	26	1.5	0.37	1.3
187	1.0	1.8	0.34	nd	0.20
126	nd	0.50	nd	nd	nd
128	1.3	3.5	nd	nd	nd
201	nd	nd	nd	nd	nd
180	1.5	3.4	0.51	0.26	0.24
170	1.4	3.2	0.30	0.18	0.22
195	nd	nd	nd	nd	nd
194	0.28	0.77	nd	nd	nd
206	1.3	2.5	1.0	0.42	0.43
209	0.35	0.72	0.32	0.10	0.039
Σ PCB	32	64	5.4	1.4	2.8

7.3 Chlordane Congener GC Concentrations (ng/g)

Sample ID Congener	GY18-19 Csamp [ppb]	GY16 Csamp [ppb]	GY24 Csamp [ppb]	GY23 Csamp [ppb]	GY20 Csamp [ppb]	GY3 Csamp [ppb]	GY39-41 Csamp [ppb]	GY6 Csamp [ppb]	GY10 Csamp [ppb]	GY36-37 Csamp [ppb]	BM20 Rep. 1 [ppb]	BM20 Rep. 2 [ppb]
heptachlor	0.59	7.56	0.249	0.304	0.388	nd	nd	nd	0.177	nd	nd	nd
oxychlordane	1.48	13.6	nd	nd	0.998	nd	nd	nd	1.99	nd	0.414	nd
hepta epoxide	1.33	49.1	0.455	nd	0.264	nd	nd	nd	2.89	nd	nd	nd
g-Chlordane	34.1	345	9.16	5.34	20.0	4.51	0.841	0.308	8.34	1.08	0.524	0.360
a-Chlordane	20.6	219	5.62	2.52	11.7	2.97	0.343	nd	2.52	nd	0.450	0.295
trans-nonachlor	14.2	152	5.88	2.22	8.78	1.97	0.123	0.431	2.84	0.758	1.87	1.04
cis-nonachlor	6.38	8.06	1.36	nd	3.64	0.719	nd	nd	1.20	0.311	4.20	1.41
Σ chlordane	78.7	795	22.7	10.4	45.7	10.2	1.31	0.740	19.9	2.15	7.46	3.10

Sample ID Congener	BM2 Csamp [ppb]	BM4 Csamp [ppb]	BM13 Csamp [ppb]	BM17 Csamp [ppb]	BM21 Csamp [ppb]	BM24 [ppb]	BM26 Csamp [ppb]	BM25 Csamp [ppb]	RIS10 Csamp [ppb]	RIS6 Csamp [ppb]	RIS2 Csamp [ppb]	RIS7 Csamp [ppb]	RIS35 Csamp [ppb]	RIS40 Csamp [ppb]
heptachlor	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.306	nd
oxychlordane	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.746	nd
hepta epoxide	nd	nd	nd	nd	nd	nd	nd	nd	nd	2.02	nd	nd	0.469	nd
g-Chlordane	0.160	0.163	0.565	nd	0.525	1.25	0.438	0.176	2.39	0.349	0.730	0.694	3.11	0.385
a-Chlordane	nd	nd	nd	nd	nd	0.174	0.220	nd	0.679	nd	0.295	nd	0.698	nd
trans-nonachlor	0.564	nd	0.631	0.194	0.420	nd	0.862	0.264	1.27	0.174	0.722	nd	2.42	nd
cis-nonachlor	0.598	nd	0.354	nd	nd	0.389	0.680	0.706	0.719	nd	0.242	nd	1.59	nd
Σ chlordane	1.32	0.16	1.55	0.194	0.94	1.81	2.20	1.15	5.06	2.54	1.99	0.69	9.34	0.38

Sample ID Congener	EMF28-29 Csamp [ppb]	EMF30-37 Csamp [ppb]	EMF7-14 Csamp [ppb]	EMF11-18 [ppb]	EMF22-23 Csamp [ppb]	EMF1-6-6a Csamp [ppb]	EMF2a-4a Csamp [ppb]	EMF24-25 Rep. 1 [ppb]	EMF24-25 Rep. 2 [ppb]
heptachlor	nd	nd	nd	nd	nd	nd	nd	nd	nd
oxychlordane	nd	0.490	1.46	0.150	0.377	0.497	0.270	nd	nd
hepta epoxide	nd	nd	nd	nd	nd	nd	nd	nd	nd
g-Chlordane	0.306	0.692	3.19	0.728	0.549	nd	1.17	0.593	0.660
a-Chlordane	nd	0.704	6.94	2.11	0.649	1.84	1.50	0.462	0.550
trans-nonachlor	nd	7.37	22.7	nd	5.52	7.51	6.22	2.63	3.13
cis-nonachlor	1.22	0.387	20.6	0.868	3.40	4.63	2.39	1.07	1.32
Σ chlordane	1.53	9.64	54.9	3.85	10.5	14.5	11.5	4.75	5.66

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March 16, 2015

Via U.S. Mail and Electronic Mail

Mr. Galo Jackson
Remedial Project Manager
U.S. EPA Region 4
61 Forsyth Street, SW
Atlanta, GA 30303

Re: Comments on LCP Chemicals Superfund Proposed Plan

Dear Mr. Jackson:

We submit these comments on behalf of One Hundred Miles, the Satilla Riverkeeper, and the Altamaha Riverkeeper, as well as the collective memberships of all of these organizations. How the LCP Chemical Site is remediated is of great concern to each of these partner groups. We feel there are serious shortcomings in the U.S. Environmental Protection Agencies' (EPA) Superfund Proposed Plan for operable unit 1 of the Site, as well as the underlying Remedial Investigation and Feasibility Study prepared by the potentially responsible parties.

In short, the Proposed Plan is flawed in the following ways: i) the scope of the cleanup does not encompass all the contamination from the Site, ii) portions of the Site have not been adequately sampled, iii) the exposure levels are not sufficiently protective, iv) some alternatives would allow for the capping and covering of contaminants in place despite the very volatile marsh environment; v) no alternative discusses marsh restoration; vi) none of the alternatives take into account sea level rise; vii) none of the alternatives set forth a monitoring plan; and in the event the contamination caps and covers were to fail, the Proposed Plan does not specify what action would be taken to remedy the situation.

As part of our comments we have attached expert reports from Dr. Philip B. Bedient, P.E., Ph.D. and Loren Raum, Ph.D. These reports detail many of the flaws outlined above.

Background

The marsh component of the LCP Chemicals Site is approximately 700 acres in size. It is located in the Turtle River estuary immediately outside of Brunswick, Georgia. The Site primarily consists of tidal marsh and is divided in half, north to south, by Purvis Creek. Over the past 70 years, a number of industrial facilities operated on the Site, such as Atlantic Refining Company, Georgia Power, and Honeywell International Inc., and each one significantly contributed to the contamination of the Site's soil, groundwater, and marsh sediment. This section will briefly discuss the Site's history and cleanup progression.

In 1919, the Atlantic Refining Company owned and operated an oil refinery on the Site, the first manufacturing facility on record. The Georgia Power Company purchased portions of the land from the Atlantic Refining Company in 1937, 1942, and 1950 for electric power generating. From 1941 to 1955, the Dixie Paints and Varnish Company manufactured paint and varnish on the property. The Allied Chemical and Dye Corporation subsequently purchased most of the property (including the portions owned by Georgia Power and Dixie Paints and Varnish), and operated a chlor-alkali chemical plant. The primary purpose of this facility was to produce sodium carbonate from salt, ammonia, and carbon dioxide. In 1979, Linden Chemicals and Plastics (LCP Chemicals-Georgia, Inc.) acquired the Site and continued operating it as a chlor-alkali facility. LCP Chemicals ceased production in 1994.

As a result of decades of contamination, the EPA (through its federal enforcement power) ordered the previous property owners to begin cleaning up the Site in 1994. These previous owners, or potentially responsible parties, included the Atlantic Richfield Company, Georgia Power, and Honeywell. The following year, the state of Georgia designated the Site as its highest priority release, and requested that EPA add it to the National Priorities List. The National Priorities List is "a list of the most serious sites identified for possible long-term cleanup," and is based on the site's potential release of hazardous substances or contaminates.[1] LCP Chemicals was officially added to the EPA National Priorities List in 1996. Subsequently, from 1998-1999, EPA conducted its own removal action, removing over 200,000 tons of hazardous material and removing and

[1] U.S. Environmental Protection Agency, "Superfund Cleanup Process," *available at* http://www.epa.gov/superfund/cleanup/index.htm, (last visited Mar. 5, 2015).

restoring approximately 13 acres of marsh from the Site. The EPA and the potentially responsible parties agreed to share the cost of this removal effort.

After the National Priorities List designation and the removal action, the potentially responsible parties conducted a series of investigations in order to draft a remedial investigation report and feasibility study for the LCP Chemicals marsh area. Upon review of these documents, EPA issued a Proposed Plan for cleaning up the marsh, which includes a number of alternatives based on the findings from the Feasibility Study. In the Proposed Plan, EPA selected the "preferred" cleanup alternative. The public is permitted to submit comments, like the ones in this document, relating to that preferred alternative. Once the public comment period closes and EPA revises the Proposed Plan based on the public's feedback, the agency will issue a Record of Decision, which will explain the cleanup alternative ultimately selected for the LCP Chemicals Site.

Comments

I. The potentially responsible parties have drawn the boundaries of the area that needs to be addressed by the LCP Chemical Site cleanup too narrowly.

Although the property boundaries of the marsh portion of the LCP Chemicals Site may only encompass 700 acres, the breadth of contamination is far greater. The potentially responsible parties have left a legacy of contaminants that stretches far beyond the Turtle River estuary. A recent study conducted by the Agency for Toxic Substances and Disease Registry concludes that the specific PCBs used at LCP Chemicals, Aroclor 1268, is widespread in sediments around Brunswick.[2] The study revealed, for instance, that residents from Sapelo Island have been exposed to Aroclor 1268 and have elevated levels of PCBs in their bloodstreams as a result.[3] The most likely way that the residents became exposed to the Aroclor 1268 was by eating fish and other sea food that had consumed Aroclor 1268 from the LCP Chemicals Site. Sapelo Island is over 30 miles

[2] Backer, Lorraine and David Mellard, Polychlorinated Biphenyls (PCBs) in Georgia Coastal Environments and Populations, (Powerpoint slides), Agency for Toxic Substances and Disease Registry, p. 8 (Sept. 3, 2014).
[3] *Id.* at 26.

from the LCP Chemicals Site, so it is likely residents throughout the coastal Brunswick area are impacted as well.[4]

Before this cleanup advances, the potentially responsible parties should be required to address their full contamination legacy. The fish and other seafood that is currently contaminated with LCP Chemical contaminants will continue to be caught and consumed by recreational and subsistence fishermen. Even if institutional controls are instituted on a wider scale, as the ATSDR study recommends,[5] funds should be established for cancer victims in the Brunswick area and funds should be established for local food banks to compensate subsistence fishermen that depend on seafood for their protein. In addition to these measures, the potentially responsible parties should fund the natural resource damage projects required by the Natural Resource Trustees. Unless the potentially responsible parties undertake measures such as these, they will not make the public whole for injuries that may have occurred as a result of contamination from the Site.[6]

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[4] It is well established that "the government need not trace or 'fingerprint' a defendant's wastes in order to recover under CERCLA." *United States v. Hercules, Inc.*, 247 F.3d 706, 716 (8th Cir. 2001), citing *United States v. Monsanto,* 858 F.2d 160, 169–70 (4th Cir. 1988).

[5] Backer at 26.

[6] Restoration Planning Scoping Notice, LCP Chemicals, Brunswick, Georgia (May 31, 2006).

II. The sampling on the Site is inadequate in areas such as Purvis Creek.

As Dr. Bedient commented in his expert report, the

> [s]ampling network used to delineate areas that need remediation is lacking in density and frequency. From figure 6-5 it is clear that approximately 50% of Purvis Creek has not been sampled for contaminants of concern. It is more likely than not that many of these non-sampled areas are contaminated with contaminants of concern.[7]

Without an adequate sampling network, the Site's contamination cannot be properly delineated. Before the Feasibility Study is finalized, the potentially responsible parties must complete an adequate sampling network and revise the Feasibility Study accordingly.

III. The exposure levels selected do not adequately protect human health and the environment.

In selecting remedial actions, the EPA is directed to establish acceptable exposure levels that are protective of human health and the environment and shall be developed by considering the following ... [f]or systemic toxicants, acceptable exposure levels shall represent concentration levels to which the human population, including sensitive subgroups, may be exposed without adverse effect during a lifetime or part of a lifetime, incorporating an adequate margin of safety.[8]

In performing this task for the LCP Chemical Site, the potentially responsible parties have failed to take into account site specific aspects of the Brunswick area and thus have based cleanup alternatives in the Proposed Plan on improper exposure levels.

For known or suspected carcinogens, acceptable exposure levels under the NCP are generally concentration levels that represent an excess upper bound lifetime cancer risk to an individual of between 10^{-4} and 10^{-6} using information on the relationship between dose and response.[9] In other words, one additional person in 10,000 to one additional

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[7] Philip Bedient, Review of the LCP Chemicals Site, Brunswick, GA, Expert Report (Mar. 13, 2015) (Attachment A).
[8] 40 C.F.R. § 300.430(e)(2)(i).
[9] 40 C.F.R. § 300.430(e)(2)(i)(A)(2).

person in 1,000,000 will contract cancer as a result of exposure to the site. There is no requirement that a certain number of people be exposed. Rather, the NCP requirement is designed to protect an individual from an increased risk of contracting cancer as a result of exposure to hazardous substances.

A. The human health exposure levels are not protective enough.

1. The risk assessment underestimates the consumption of contaminated food.

The exposure level for human health was based in part on the number of seafood meals a subsistence fisherman would consume on a yearly basis. This number was "assumed" by the potentially responsible parties to be 40 meals per year.[10] This assumption was not based on any recent surveys of subsistence fishermen in the area.[11] Fortunately, there is a relevant study now. The ATSDR study mentioned above reveals that subsistence fishermen in the area consume up to 156 seafood meals a year—nearly four times the amount assumed by the potentially responsible parties.

Unless the potentially responsible parties take this differential into account and recalculate the exposure levels, they will be drastically underestimating the contaminants that will be consumed from the Site. In other words, subsistence fishermen have been and will continue to be exposed to more Aroclor 1268 and other contaminants from the Site than the Remedial Investigation report reveals.

The potentially responsible parties also erred in their treatment of adolescent subsidence fishermen. While it may be true that adolescent subsidence fishermen may fish less frequently than their parents, this has no bearing on how often they consume fish for supper. Most adolescents eat whatever ends up on the dinner table. Yet, the potentially responsible parties, for their risk modeling, contend that adolescent subsidence fishermen eat a full third less fish than their parents.[12] This does not square with reality and serves as another example of how the potentially responsible parties have underestimated the amount of exposure that subsidence fishermen would suffer even after the cleanup if it were done on the potentially responsible parties' terms. This is especially

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[10] Proposed Plan at 16.

[11] Raun at 7.

[12] Human Health Risk Assessment for the Estuary, Operable Unit 1, Marsh Trespasser, Fish and Shellfish Consumer, Clapper Rail Consumer, Final, LCP Chemical Site, Brunswick, Georgia, Table 14a and Table 14b (Aug. 2011).

alarming considering that Site is very accessible to boats; as the Draft Feasibility Study states, boats up to 14 feet in length can access the Site using Purvis Creek.[13]

And the issue of subsistence fishing cannot be corrected by increasing fishing advisories. As other studies provide, subsistence fishermen do not pay attention to fishing advisories. "People are often aware of advisories, but continue to consume fish nonetheless (Reinert and other 1991, Burger and Gochfeld 1991, Burger and others 1992, 1993, Velicer and Knuth 1994, May and Burger 1996).[14] This is not surprising since fish "may be the main affordable source of protein."[15] And as Dr. Raun states in her expert report, "[f]ishing advisories will not keep hungry community members from eating contaminated seafood."[16]

2. The potentially responsible parties assumption that there has been a decrease in fish contamination is flawed.

The potentially responsible parties contend that the concentration of contaminants in fish has decreased, yet they offer no statistically significant evidence of this assumption. As Dr. Raun states in her expert report, the potentially responsible parties' contentions are largely overstated.[17] They are based on small sample sizes with limited statistical power, are unsophisticated, and tend toward bias.[18] Furthermore, the risk assessment does not acknowledge that a subsidence fisherman may eat more than one type of seafood, and the impact may be additive. As Dr. Raun points out in her report, "[t]his type of simplification is not protective with multiple contaminants impacting many different types of seafood."[19]

3. The potentially responsible parties did not take groundwater, surface water, and operable unit 3 into account.

The potentially responsible parties admit that contaminated groundwater is coming to the surface through seeps and mixing with surface water around the area that was

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[13] Draft Feasibility Study at 10.
[14] Burger, Joanna, et al., Science, Policy, Stakeholders, and Fish Consumption Advisories: Developing a Fish Fact Sheet for the Savannah River, 27 Environmental Management No. 4 p. 502 (2001).
[15] *Id.*
[16] Raun at 10.
[17] *Id.*
[18] *Id.* at 8-9.
[19] Raun at 8.

remediated in 1999. They contend, however, that the surface water dilutes the contamination to such an extent that it is not a factor. Dr. Raun disagrees. She views the increased levels of contamination in the formerly remediated area as evidence that whatever dilution that is taking place is not sufficient offset the groundwater contamination.[20] The potentially responsible parties must demonstrate that contaminated groundwater is not a problem at Site, or develop a plan for addressing it.

Additionally, the risk assessment does not take into account other pathways aside from fish consumption. As Dr. Raun states in her report,

> [r]isk assessment requires that all exposure pathways for a receptor be considered. . . . In other words, the risk for the high rate consumer should be added to the risk of receptors considered in the OU3 risk assessment, and RGOs developed based on the added risk. While it is acceptable to separate the contamination into operable units for management, it is not justifiable to consider the risk in an operable unit in a vacuum.[21]

For example, a subsidence fisherman could well be a trespasser on operable unit 3. The risk assessment must take into account both contaminant pathways. Similarly, the risk assessment does not take into account exposure to contaminated surface water and sediments from the Site. As Dr. Raun states in her report, "Any risk added from these other pathways would result in lower [remedial goals]."[22]

B. The ecological exposure levels are not protective enough.

In addition to using numbers that artificially reduce the exposure levels to humans, the potentially responsible parties have done the same for the environment. Starting in 2006, the Georgia Department of Natural Resources, NOAA Fisheries, and the National Ocean Service began to test bottlenose dolphin in the Brunswick area for PCB contamination. In particular they focused on Aroclor 1268.[23] As the study provides, "[b]ottlenose dolphins are ideal sentinels for coastal ecosystem health because they are top predators that are long-lived and tend to accumulate persistent environmental

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[20] Raun at 5.
[21] *Id.* at 3.
[22] *Id.*
[23] Georgia Department of Natural Resources, Bottlenose Dolphin Contaminants Project, http://www.georgiawildlife.org (last visited Feb. 26, 2015).

contaminants in their lipid-rich blubber."[24] The findings of the study reveal that the dolphins tested had concentrations of Aroclor 1268 ten times higher than any location previously documented.[25]

Even though the dolphin study was ongoing, was investigating the precise contaminant at issue at the LCP Chemical Site, and involved the "ideal sentinel for ecosystem health," the potentially responsible parties did not incorporate the data in their risk assessment. Nor did they test any dolphins themselves, even though they acknowledge that dolphins do visit the Site via Purvis Creek, the main tidal creek that connects the Site to Turtle River.[26] Instead of testing dolphins, the potentially responsible parties chose marsh rabbits, river otters, and raccoons for their ecological risk assessment.[27] The potentially responsible parties should be required to redo their ecological risk assessment so that it either incorporates existing data from the dolphin study or incorporates new data gathered by the potentially responsible parties.

The potentially responsible parties set as one of their remedial action objectives to "reduce piscivorous [fish eating] bird and mammal population exposure to [contaminants] from ingestion of prey exposed to contaminated sediment in the LCP Chemicals marsh to acceptable levels, considering spatial forage areas of the wildlife and movement of forage prey."[28] Yet the potentially responsible parties did not include the piscivorous mammal most prone to bioaccumulation in any of its analyses—the bottlenose dolphin.[29] This flaw must be corrected.

C. The exposure range selected is not acceptable.

Not only did the potentially responsible parties underestimate the amount of risk associated with exposure to the contaminants of concern, they then selected exposure levels based on the absolute lowest allowable risk factor—an additional cancer victim in every 10,000 people (1E-04).[30]

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[24] *Id.*
[25] *Id.*
[26] Draft Feasibility Study at 12.
[27] Proposed Plan at 21.
[28] Proposed Plan at 23.
[29] Draft Feasibility Study17 and 18.
[30] Proposed Plan at 24.

As the potentially responsible parties report in the draft feasibility study, "[o]nly the high-quantity fish consumer scenario has an ELCR estimate that exceeds USEPA's target risk range of 10^{-6} x to 10^{-4} and that estimate is 2 x 10^{-4}."[31] In other words the potentially responsible parties have proposed an exposure level for subsidence fishermen twice as high as EPA typically accepts. According to EPA guidance, to have a target risk of less than 1 x 10^{-4}, there must be site specific reasons that support such a departure.[32] The potentially responsible parties provide no site specific reasons that would justify such a change. Thus, not only have the potentially responsible parties underestimated the number of fish meals that subsidence fishermen eat per year, but they have compounded the problem still further by subjecting subsistence fishermen to higher exposure levels.

D. The potentially responsible parties want to leave contaminant hot spots in the marsh.

To compound the exposure level flaws still further, the potentially responsible parties also apply a concept called "surface weighted average concentration" which would, if the Proposed Plan were to go through, leave hot spots of contamination in the marsh.[33] Instead of cleaning the entire marsh up to a set level of contamination, the potentially responsible parties are proposing to leave areas of higher contamination in the marsh because they are more difficult to dredge. This is unacceptable. The potentially responsible parties should not be allowed to ignore contaminated areas because they are hard to reach.

IV. The thin layer cover approach used in Alternative 2 is inappropriate for this Site.

A. The Site is a volatile marsh environment unsuitable for a thin layer cap.

In the Superfund Proposed Plan, the U.S. Environmental Protection Agency and the Georgia Environmental Protection Division (the Agencies) provide, "[t]he Turtle River water surface elevation can vary in excess of nine ft during a tidal cycle."[34] In the Draft Feasibility Study, the potentially responsible parties acknowledge that "[t]idal

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[31] Draft Feasibility Study at 21.
[32] *Id.* at 20.
[33] Proposed Plan at 24.
[34] U.S. Environmental Protection Agency, Superfund Proposed Plan, LCP Chemicals Superfund Site, Operable Unit 1, Nov. 2014, at 3.

hydrodynamics have a significant effect on the transport of waterborne substances (e.g., suspended sediment, chemicals) within the Site." And that the 7-8 foot tide range "produces strong vertical mixing in the water column and a relatively long horizontal excursion of water."[35] The potentially responsible parties state further that "[c]urrent velocities are relatively high within the tidal creeks during flood tide."[36] Lastly, the potentially responsible parties admit that "[s]ediment erosion is likely to occur in some portions of the tidal creeks during spring tide conditions because peak current velocities are high enough . . . to exceed the critical shear stress of surface sediments . . . ."[37]

Despite the above descriptions of the Site that reveal it is a highly volatile environment, the potentially responsible parties contend that they can cover contaminants in place with a six-inch layer of sand and that it will all hold together through high tides, hurricanes, and storm surges.[38] As the EPA has stated in guidance, "[t]ypically, sand caps are used in low velocity waterways to protect them from scouring by strong (high energy)

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[35] Draft Feasibility Study at 8.
[36] *Id.* at 8.
[37] *Id.* at 9.
[38] Brunswick is no stranger to hurricanes and tropical storms as the following records document:

> 1874 Sept. 28th a hurricane from the SW stays just offshore with 80mph winds
> 1878 Sept. 12th just offshore moving north 90 mph
> 1885 Aug. 25th just offshore 105mph while moving north
> 1893 Aug. 28th a major hurricane with 115 mph winds just east kills over 2,000 in Georgia & Carolinas, reports had downtown Brunswick under 6 ft. of water for up to 12 hrs., offshore of St. Simons Island by 25-30 statute miles. . . .
> 1893 Oct. 13th just off shore while moving NNE 120 mph winds
> 1896 Sept. 29th a cat 2 110 mph passes over while moving N.E. Winds caused very heavy damage in the area.
> 1898 Oct. 2nd, 130 mph from the S.E. a hurricane leaves area under 4 ft. of water Oct. 2nd scores drowned. Winds east at 135 mph and data suggest that this Hurricane may have been the size of Hugo (1989 S Carolina). Calm reported at 11 am, Dunn and Miller reported 179 killed in coastal Georgia and 16 foot storm surge in downtown Brunswick. . . .
> 1928 Sept 18th from the south just inland with 90 mph winds
> 1968 tropical storm Abby 60 mph minor damage
> 1979 Sept 4th David to east by 30 miles with 85 mph winds minor damage.
> 1981 tropical storm Dennis to east with 50mph winds minor damage
> 1984 tropical storm Isadore passed over the area from the south west with 45mph minor damage.

Glynn County, Brunswick, Georgia's history with tropical systems, http://www.hurricanecity.com/city/brunswick.htm (last visited Feb. 27, 2015).

currents.[39] As mentioned above, the potentially responsible parties admit that there will be erosion along tidal creeks on the Site. As one study involving a Georgia marsh reported, roughly 10 to 25% of the marsh surface is occupied by creek banks and tall S. alterniflora zones.[40] With tidal creeks occupying so much surface area in Georgia marshes, there is plenty of opportunity for extensive scouring on the LCP Chemical Site.

Furthermore, as Dr. Bedient provides in this comments, the Site conditions simply are not suitable to a thin layer cap.[41] As he states,

> Placing a cap or thin sand cover on top to the contaminated sediment in the marsh would not prevent such erosion/scour given the volatile nature of the tidal regime and water level fluctuations during storm events (see Figure B3-15 from the Feasibility Report June 2014), especially since there is no tie-in into the existing marsh sediment so as to completely contain the contaminated sediment from being able to migrate.[42]

In short, the LCP marshes are no place for a thin layer cap.

Nonetheless, to support their choice of a thin layer placement approach, the potentially responsible parties include in the Draft Feasibility Study eight case studies of other remediations that have used this cover-in-place method; however, not one the projects combined 6 inch sand cover, a marsh environment, and a 9 foot tide. Furthermore, some of the projects were totally dissimilar and involved putting the thin cover on the floor of the rivers, inlets, or harbors.[43]

The remediation performed at one of the case studies, Bremerton Naval Complex, for example, involved thin-cover placement on the bottom of Sinclair Inlet offshore from a naval shipyard.[44] And the effectiveness of the project is still being evaluated.[45] Another

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[39] EPA, Contaminated Site Cleanup Information, http://clu-in.org/contaminantfocus/default.focus/sec/sediments/cat/Remediation/p/1 (last visited Feb. 22, 2015).
[40] Gribsholt, Britta, et al. Impact of fiddler crabs and plant roots on sediment biogeochemistry in a Georgia saltmarsh, 259 Mar. Ecol. Prog. Ser. 248 (Sept 12, 2003).
[41] Bedient at 4.
[42] *Id.*
[43] Draft Feasibility Study at 53.
[44] Merritt, K. et al., Enhanced Monitored Natural Recovery (EMNR) Case Studies Review, Technical Report 1983, p. 16, (May 2009).
[45] *See*, USGS, Sources of Mercury in Sinclair Inlet, http://wa.water.usgs.gov/projects/sinclair (last visited Feb. 24, 2015).

case study, Grasse River, involved the placement of a 12-inch cap on the bottom of a freshwater river.[46] A third involved another subaquaeous cap in Eagle Harbor in Pugent Sound.[47] A fourth involved a 9-12 inch thick cap placed at the bottom of the Lower Duwamish Waterway, in Washington. And a fifth involved the placement of a cap at a depth of 120 feet in Ward Cove in Alaska. This cap was placed over sediments that were already within human health and environment limits.[48]

The remaining case studies involved thin layer caps that were placed on tidal flats, but none involved the volatile marsh environment contemplated here. In short, the thin-cover placement technology is still in its infancy when it comes to the marsh environment. The eight case studies the potentially responsible parties have offered up are all too dissimilar from the LCP Chemicals Site to offer much comfort that a thin layer cap will perform adequately at the Site. As Dr. Bedient commented in his expert report, "[t]he experience that these concepts may have at other sites is not relevant to this site if the other sites do not have the kind of tidal regime and flood/hurricane conditions that exist at this site."[49]

If there are projects in which the thin layer cap approach has been used successfully in a marsh environment, the potentially responsible parties should be required to document these successes in the final feasibility study and discuss how those successes demonstrate that a thin layer cap could work in the volatile LCP Chemical environment. While the potentially responsible parties are correct when they say "[t]hin-cover placement is a readily implementable technology, *particularly in low-energy areas not subject to scour or erosion . . .*,"[50] with its 9 foot tide range, the Site cannot be considered "low energy."

B. The integrity of the thin layer cap will be compromised by bioturbation.

While the potentially responsible parties acknowledge that the thin cover cap will have holes poked in it by marsh organisms that will come to inhabit it, they do not consider that a problem. The potentially responsible parties contend that most of the organisms that would perform such work would be confined to the top 4 inches of the

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[46] Merritt at 26.
[47] *Id.* at 3.
[48] *Id.* at 7.
[49] Bedient at 5.
[50] Draft Feasibility Study at 54.

cover.[51] Yet, the potentially responsible parties state earlier in the Draft Feasibility Study that "fiddler crabs are ubiquitous in salt marshes."[52] One study reported that as many as 500 fiddler crabs can inhabit a square meter of marsh.[53]

Because of their numbers, "fiddler crabs are one of the principal agents of bioturbation in interlude salt marshes."[54] And fiddler crabs burrow far more deeply than 4 inches. The burrows typically range up to 10 inches in depth.[55] As the EPA has stated in guidance, "[t]he cap has to be at least as thick as the large populations of burrowing benthic organisms to keep them from becoming contaminated."[56] Thus, fiddler crabs on the LCP Chemical Site would regularly penetrate the 6 inch cap. As Dr. Bedient states in his report: "6 inches of sand is not sufficient to prevent sediment dwelling organisms from borrowing into and through the sand so as to expose the contaminated sediment to erosion."[57] In light of this bioturbation, the six-inch thin cap is unsuitable for this remediation.

C. The potentially responsible parties ignore sea level rise.

If the sea level rises at the rates estimated, 1-2 feet over the next 100 years,[58] the entire LCP Chemical marsh could be drowned out and replaced with mudflats. Although the potentially responsible parties contend that the Site is a "net depositional zone" because the marsh grass acts to slow the velocity of the tidal waters,[59] they need to evaluate if that were the case if the marsh grass were no longer present. Because the Draft Feasibility Study only explores the current conditions of the marsh and fails to include any discussion of how those conditions will likely change over time, it is inadequate and fails to discuss a long-term solution.

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[51] *Id.* at 52.
[52] *Id.* at 11.
[53] Gribsholt at 238.
[54] McCraith, Barbara J., et al., The effect of fiddler crab burrowing on sediment mixing and radionuclide profiles along a topographic gradient in a southeastern marsh, 61 Journal of Marine Research, 359, 359 (2003).
[55] Gribsholt at 238.
[56] EPA, Contaminated Site Cleanup Information, http://clu-in.org/contaminantfocus/default.focus/sec/sediments/cat/Remediation/p/1 (last visited Feb. 22, 2015).
[57] Bedient at 4.
[58] *Id.* at 4.
[59] Draft Feasibility Study at 8.

D. Summary of flaws with thin cap technology.

Dr. Bedient summed up his analysis of the thin layer cap application in the following:

The proposed cap will probably fail for [the] reasons listed below:

- Destruction of capping/cover material by scouring due to tidal action.
- Destruction of capping/cover material by hurricane type storms.
- Destruction of capping/cover material by changing hydraulic conditions due to sea-level rise.
- Destruction of capping/cover material by changing environmental conditions typically associated with meandering creeks within delta systems.
- Destruction of capping/cover material by sediment dwelling organisms.
- Lateral movement of contaminants within the subsurface sediment has not been addressed.[60]

In short, thin-cover placement is not an implementable technology for the LCP Chemicals Site and should not be used.

VI. The Draft Feasibility Study is incomplete because it does not include any alternatives that incorporate marsh restoration.

The potentially responsible parties admit that 700 acres of the marsh are contaminated to a level that would in certain circumstances trigger a cleanup of all 700 acres.[61] But then the potentially responsible parties explain that such a cleanup at this Site is not practical because it would cause "unwarranted harm" to the marsh.[62] Even the cleanup of 81 acres of the marsh was deemed so excessive that it was not even considered in the alternative cleanup approaches.[63] What is conspicuously lacking from this discussion is mention of any form of marsh restoration.

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[60] Bedient at 7.
[61] Proposed Plan at 24.
[62] *Id.*
[63] Proposed Plan at 25.

In their analysis, the potentially responsible parties simply assume that if they were to dredge areas of the marsh that they would have to be left in that state with perhaps some minimal backfilling. By failing to discuss what would be involved in restoring any dredged areas with adequate sediment replacement and replanting, the potentially responsible parties have failed to complete an adequate Draft Feasibility Study. This failure is particularly conspicuous considering that during the removal action on the Site, the EPA demonstrated that it could successfully dredge contaminated sediments from the marsh, backfill the dredged area, and replant the marsh. The EPA performed this restoration on the 13 most highly contaminated acres of the marsh.[64] The Draft Feasibility Study and the Proposed Plan are completely devoid of any explanation as to why the potentially responsible parties could not do what EPA has done, dredge, backfill, and restore the marsh.

From the description of the 13-acre marsh restoration that was conducted in 1998-99, the restoration was highly successful. As the Draft Feasibility Study reports, "[w]ithin two years after remediation, *Spartina* filled the remediated area of the Site . . . . After three to four years, the area was virtually indistinguishable from the surrounding marsh . . . ."[65] The Draft Feasibility Study goes on to state that "[t]hese site-specific restoration time frames are consistent with other observations noted for created salt marsh sites."[66]

As the potentially responsible parties acknowledge, the "removal of sediment by dredging or excavation has been demonstrated at numerous sites" and is a "mature" technology,[67] and the "industry and the region have substantial experience" with this form of remediation.[68] The industry is also developing experience in how to regrow marshes. In addition to the marsh that was regrown on Site, there are numerous successful marsh restoration projects across the country.[69] The potentially responsible parties should be required to explain in the Draft Feasibility Study why it did not incorporate marsh restoration into the alternatives it outlined.

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[64] *Id.* at 6.
[65] Draft Feasibility Study at 14; Raun at 10.
[66] *Id.* at 14.
[67] *Id.* at 63.
[68] *Id.* at 63.
[69] See, e.g., Florida Department of Environmental Protection, Project Greenshores, http://www.dep.state.fl.us/northwest/Ecosys/section/greenshores.htm (last visited Feb. 27, 2015).

Such analysis is particularly important considering that the potentially responsible parties rely so heavily on the concept that thin cover placement is better than dredging and backfilling the Site because a thin cover cap would have fewer short-term impacts on the marsh. But in reaching this conclusion, the potentially responsible parties are making an apples to oranges comparison. They should be comparing the thin layer cap to a dredged, backfilled, and *replanted* marsh. Because the Draft Feasibility Study does not include such a comparison, it is incomplete.

VIII. The Proposed Plan and the Draft Feasibility Study provide for inadequate information on monitoring.

As Dr. Bedient provides in his expert report, considering the nature of the thin layer cap and its vulnerability to hurricanes, tides, and storm surges, the Proposed Plan and Draft Feasibility Study should include more detailed information on monitoring.[70] For example, other thin layer cap sites have instituted monitoring plans that operate on a two-year interval.[71] Will the potentially responsible parties adopt such an interval or not? Furthermore, there is no discussion in the Draft Feasibility Study or the Proposed Plan that explains what course or courses of action will take place in the event one or more elements of the remediation were to fail. By failing to include such details, the EPA and the potentially responsible parties have denied the public its right to comment.

IX. The cap-in-place alternatives should be discarded because they do not provide a permanent solution.

The National Contingency Plan provides as follows:

> (E) Each remedial action shall utilize *permanent* solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable.[72]

Because the LCP Chemicals Site is so volatile, is subject to sea level rise, and is subject to bioturbation, it is unlikely that the thin layer caps will survive long-term.[73] Thus, it should not be considered for the LCP Chemical Site.

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[70] Bedient at 5.
[71] *See e.g.,* Merritt at 6.
[72] 40 C.F.R. §300.430 (f)(1)(ii)(E) (emphasis added).
[73] Bedient at 6.

The EPA was faced with a very similar situation to the one here involving a contaminated river in Wisconsin. One alternative involved the removal of sediment from the bottom of the river. Another involved capping that sediment in place. Even though the sediment removal option was more expensive, the EPA opted for the more permanent solution. The Seventh Circuit Court of Appeals, which eventually heard an appeal on the case, reported on the district court decision as follows:

> The district court concluded that the agencies' decision to maintain a preference for dredging in the amended remedy was rationally related to the facts before them. In particular, the court noted that dredging represents a more permanent solution because it actually removes PCBs from the Site, while capping and sand covering merely contain PCB-contaminated sediment. Moreover, capping and sand covering require long-term monitoring to ensure their effectiveness, and they are susceptible to failure during catastrophic events like floods. Ultimately, the district court concluded that the agencies acted rationally by adopting "a mild preference for the benefits of dredging and viewed these as being worth their added expense." We agree.[74]

Thus, the EPA's decision to go with the more expensive permanent solution was upheld. Similarly, if EPA were to adopt a similar course in this case, that decision too would be upheld. As this same district court explained

> Specifically, it provides that "the court shall uphold the President's decision in selecting the response action unless the objecting party can demonstrate, on the administrative record, that the decision was arbitrary and capricious or otherwise not in accordance with law." This means that the government's selected response action is presumed valid unless the Defendants can meet their burden to demonstrate otherwise.[75]

The court went on to explain that "the Defendants [had] an uphill battle: no matter how one spins it, they were demanding that more poisonous chemicals be allowed to *stay* in the River."[76] Likewise, if any of the potentially responsible parties were to challenge an EPA decision to abandon the thin layer cap approach, they would have to argue for leaving contaminants in the marsh.

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[74] *United States v. P.H. Glatfelter Co.*, 768 F.3d 662, 670 (7th Cir. 2014), *reh'g denied* (Nov. 19, 2014).
[75] *United States v. NCR Corp.*, 911 F. Supp. 2d 767, 773 (E.D. Wis. 2012) *aff'd sub nom. United States v. P.H. Glatfelter Co.*, 768 F.3d 662 (7th Cir. 2014) (citations omitted).
[76] *Id.* at 786.

There is no requirement in the NCP that EPA select the lowest cost alternative that is consistent with the plan. As the district court for the Eastern District of Arkansas explained:

> Response costs that are not inconsistent with the NCP are conclusively presumed to be reasonable and therefore recoverable under CERCLA. See *United States v. Dico,* 266 F.3d 864, 879 (8th Cir.2001); *United States v. Findett Corp.,* 220 F.3d at 849; *United States v. Hardage,* 982 F.2d at 1441-1443; *United States v. Northeastern Pharm. and Chem. Co., Inc.,* 810 F.2d at 747-48 (8th Cir.1986); *United States v. Vertac Chem. Corp.,* 33 F.Supp.2d 769, 777 (E.D.Ark.1998); *United States v. Gurley,* 788 F.Supp. at 1481. The focus of the NCP is on procedures for the selection of response action rather than on "costs", per se:
>
> > The NCP regulates *choice of response action, not costs.* Costs, by themselves, cannot be inconsistent with the NCP. Only response actions-i.e., removal or remedial actions-can be inconsistent with the NCP, which can be demonstrated by a showing that the government's choice of response action was arbitrary and capricious. As long as the government's choice of response action is not inconsistent with the NCP, its costs are presumed to be reasonable and therefore recoverable. *Hardage,* 982 F.2d at 1443 (emphasis in the original).[77]

Thus, the EPA, in making its final selection of a remedy for the LCP Chemicals Site, can and should do what it did in the river site described above, choose permanency over price.

Conclusion

Before EPA is in a position to make any choice concerning a remedy, however, the potentially responsible parties must fix the multiple flaws in the remedial investigation and feasibility study documents. The scope of the cleanup must address the fact that PCBs and other contaminants from the Site have migrated out of the Turtle River. The exposure levels must be accurately calculated. The thin layer cap must be abandoned. Sea level rise must be taken into account. Marsh restoration scenarios must be factored in. And EPA must make a choice of remedy not based on price, but on the best remedy consistent with the National Contingency Plan.

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[77] *United States v. Gurley*, 317 F. Supp. 2d 870, 878 (E.D. Ark. 2004) *aff'd,* 434 F.3d 1064 (8th Cir. 2006).

In responding to these comments, we ask that you also address any comments made in the attached expert reports.

Thank you for providing us with this opportunity to comment on this important project.

Sincerely,

William W. Sapp

William W. Sapp
Senior Attorney

cc: Megan Desrosiers, One Hundred Miles
Ashby Nix, Satilla Riverkeeper
Jen Hilburn, Altamaha Riverkeeper

ATTACHMENT A

Review of the LCP Chemicals Site, Brunswick, GA.

By Philip B. Bedient, P.E., Ph.D.

March 13, 2015

Philip B. Bedient

P. B. Bedient and Assoc., Inc

Review of the LCP Chemicals Site, Brunswick, GA.

I was retained on this project for the purpose of evaluating the potential contaminant transport from the LCP Chemicals Site into the Turtle River estuary system, here forth referred to as "the Site". My opinions are based on my professional experience in hydrogeology, environmental engineering, hydrology and hydraulics, and review of relevant data, maps, aerials, documentation to date, and are subject to change if and when additional information becomes available.

Section I. Qualifications

My educational background, research and professional experience and the review of documents provided are the basis of my opinions. I hold the Ph.D. degree from the University of Florida in Environmental Engineering Sciences, and I have attached a curriculum vita including a list of peer-reviewed publications. I am the professor of Civil and Environmental Engineering at Rice University, where I have been on faculty since 1975, and teach courses in hydrogeology, hydrology, floodplain analysis and hydrologic modeling. I have written two major textbooks, one on hydrogeology and one on hydrology. I have worked at over 30 hazardous waste sites and military bases nationwide since 1981 including over 12 Superfund Sites. I currently hold the following positions: Herman Brown Professor of Engineering, Fellow of ASCE, Diplomat of the American Academy of Water Resources Engineers, and the Director of the Severe Storm Prediction, Education, and Evacuation from Disasters (SSPEED) research center at Rice University. I am a registered professional engineer in Texas and a registered professional hydrologist.

Section II. Site History and Description

Use began in 1836 with construction of the Brunswick-Altamaha Canal along the uplands and the marsh boundary.

ARCO used Site as a refinery from 1919-1929.

Georgia Power operated an oil-fired power plant from 1937 through 1950.

Dixie Paint and Varnish Co. purchased part of the Site in 1941 and operated a manufacturing facility until 1955.

Allied Chemical purchased the Site in 1955 and constructed and operated a chlor-alkali facility, utilizing the mercury-cell process. Main products were chlorine gas, hydrogen gas, and sodium-hydroxide solution

LCP Chemicals purchased almost all of the Site in 1979 and continued to operate the chlor-alkali facility until 1994, when operations were discontinued. In May 1998, Allied Signal (Honeywell) purchased the LCP property from the estate in bankruptcy.

The LCP site occupies approximately 813 acres of tidal marshland and dry land northwest of Brunswick, Georgia, along the Turtle River estuary system.

Section III. Chemicals of Concern

- Mercury (including methylmercury)
- PCB (Aroclor 1268)
- Lead
- Polycyclic Aromatic Hydrocarbons (PAHs)

Section IV. Comments on Proposed Remedial Measures

1. **The cap/thin sand covering are subject to erosion/scour and/or failure given the volatile tidal regime in the area**

This site is located within a marsh of about 700 acres that is split by Purvis Creek, a tributary to Turtle River, and is subject to daily tides that can fluctuate from about 6 feet below mean sea level to as much as 4 feet above mean sea level (see Figure B2-18 from the Feasibility Report June 2014). Given that the marsh has a surface elevation of about 2-3 feet above mean sea level (see Figure B2-4), this means that the marsh is subjected to inundation and filling with high tide and to draining with low tide, twice a day. As such, the sediment in the marsh would be subjected to erosion/scouring and to being transported around, into and out of the marsh, both during tidal activity, as well as during rainfall/runoff conditions, especially during heavy rainfall events, floods and hurricanes. Placing a cap or thin sand cover on top of the contaminated sediment in the marsh would not prevent such erosion/scour given the volatile nature of the tidal regime and water level fluctuations during storm events (see Figure B3-15 from the Feasibility Report June 2014), especially since there is no tie-in into the existing marsh sediment so as to completely contain the contaminated sediment from being able to migrate.

2. **The cap/thin sand covering concepts are subject to disturbance by sediment dwelling organisms that inhabit the marsh area**

The thickness of the proposed cap concepts of about 6 inches of sand is not sufficient to prevent sediment dwelling organisms from borrowing into and through the sand so as to expose the contaminated sediment to erosion.

3. **The cap/thin sand covering concepts are subject to increased inundation due to sea level rise**

The proposed cap concepts do not recognize nor address the impact of sea level rise on the long-term effectiveness of these concepts to prohibit the escape of contaminants within the marsh. Estimates of sea level rise of from 1-2 feet over the next 100 years have been presented (e.g. from the USACE). Such change in the normal water levels in the area will inherently result in changes to the topography of the site and the nearby rivers,

streams, creeks, and gullies that have not been evaluated as to the long-term effectiveness of the proposed concepts.

4. **The cap/thin sand covering concepts will require long-term monitoring to ensure effectiveness**

These remedial concepts will require long-term monitoring to ensure that they are effective in containing and/or remediating the contaminated sediment at the site. There are no details as to what such monitoring will entail, as well as what actions would be taken if it is determined that these concepts are not working or fail.

5. **Movement of contaminants from under the thin sand layer is possible given the interaction of groundwater with the surface water in the marsh and the fluctuation of the tides in this area**

Given the evidence that there is groundwater interaction with the surface water and the marsh in this area, these concepts do not prevent such interaction from continuing, such that contaminants will continue to move out of the marsh and into the groundwater and surface water in the area.

6. **Previous experience at other sites not similar to this site given its volatile tidal regime in relation to the topography**

The experience that these concepts may have at other sites is not relevant to this site if the other sites do not have the kind of tidal regime and flood/hurricane conditions that exist at this site.

7. **The proposed cap areas along Purvis Creek seem to be selected based on limited sampling**

The location of dredge areas and proposed cap areas along Purvis Creek are based on the results of the selected samples taken along portions of the creek (see Figures 5-2 and 6-1C). However, there are numerous areas where no samples were taken, near to where there were samples showing high contaminant levels that will receive caps (see Figure 6-5). In addition, there were samples taken adjacent to one another that showed one to have

high levels of contamination and the other did not. This suggests that the extent of contamination is extremely variable along this creek, necessitating a much more dense sampling network than what was done, if the remedial plan is to simply cap only those areas where the samples taken showed high levels of contamination.

8. Dredging is a more permanent solution than the cap/thin sand covering concepts

These proposed remedial concepts do not permanently remove the contaminants from the area, and are subject to failure as discussed above. Dredging and removal of the contaminated sediments would be a permanent solution.

Section V. Opinions

The above review of information and findings support the following opinions:

- Chemicals of Concern have been and still are released in significant quantities into the Turtle River estuary system on a daily basis. The tidal action within the marsh area will ensure a constant exchange of sediment to and from the marsh area on a daily basis.
- The water quality in the Turtle River estuary system has continually deteriorated over the past several decades as a result of the contamination emanating from the Site. This will continue until the Site has been properly remediated.
- The location of the Site in direct proximity and connection to the Turtle River estuary system has created a major environmental impact on the immediate area as recognized by the EPA, ATSDR, GEPD, and other organizations.
- Sampling network used to delineate areas that need remediation is lacking in density and frequency. From figure 6-5 it is clear that approximately 50% of Purvis Creek has not been sampled for contaminants of concern. It is more likely than not that many of these non-sampled areas are contaminated with contaminants of concern.
- The proposed cap will probably fail for a number of reasons listed below:
    - Destruction of capping/cover material by scouring due to tidal action.

- Destruction of capping/cover material by hurricane type storms.
- Destruction of capping/cover material by changing hydraulic conditions due to sea-level rise.
- Destruction of capping/cover material by changing environmental conditions typically associated with meandering creeks within delta systems.
- Destruction of capping/cover material by sediment dwelling organisms.
- Lateral movement of contaminants within the subsurface sediment has not been addressed.

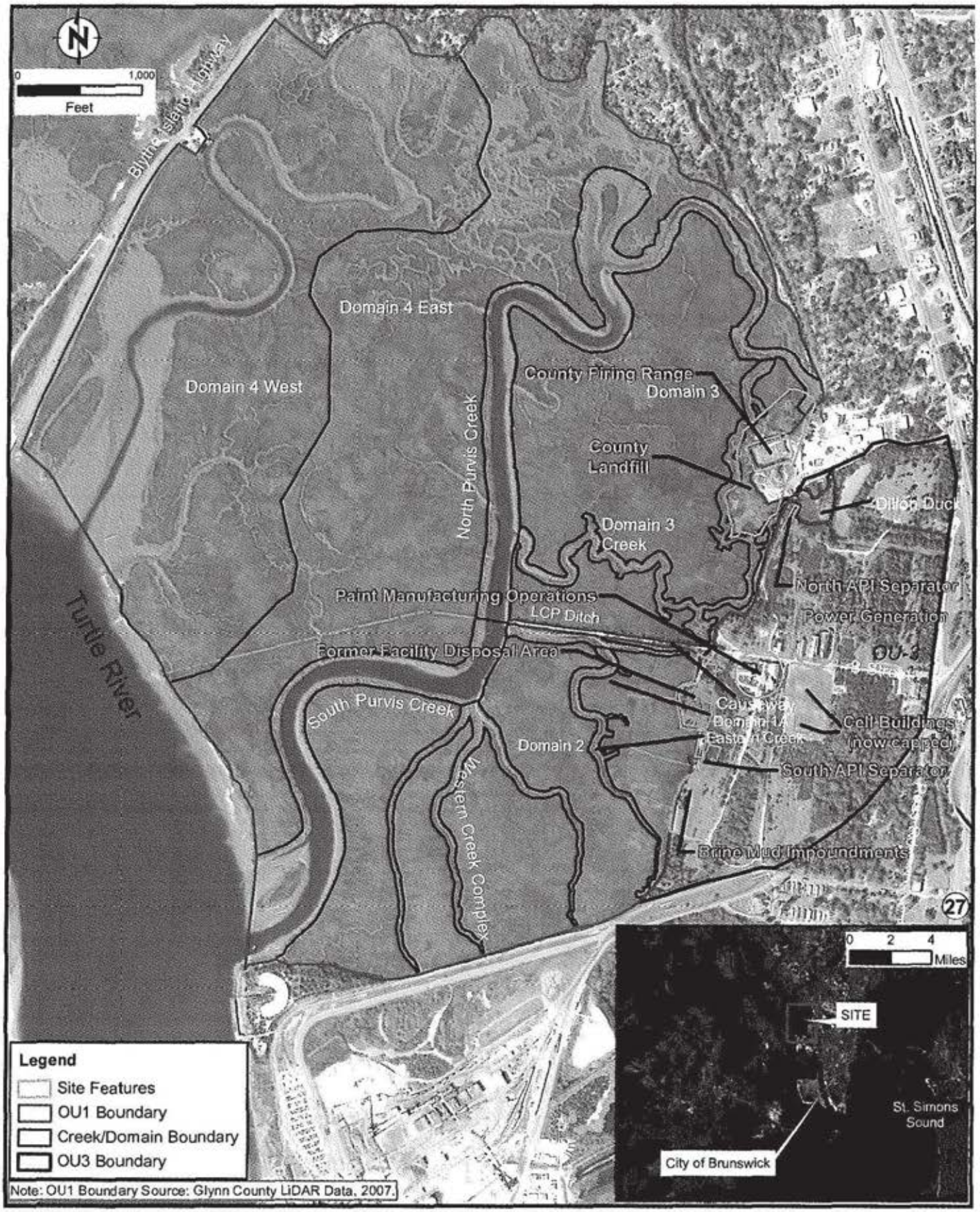
- Another major concern will be the long term monitoring that needs to take place after remediation has been implemented and action plans when remedial systems fail to protect the surrounding environment from the chemicals of concern. If the cap is constructed, it will have to be continually maintained and repaired, and this does not provide a permanent solution.

The comments, herein, are based on a preliminary review of available data to date and are subject to change. If additional information becomes available and is provided to me regarding this case, I will review it and provide supplementary opinions as appropriate.

Section VI. Documents Reviewed

1. *November 2014, U.S. Environmental Protection Agency Superfund Proposed Plan, LCP Chemicals Superfund Site, Operable Unit 1, City of Brunswick, Glynn County, Georgia*
2. *June 2, 2014 Draft Feasibility Study, Operable Unit No. 1 (Estuary), LCP Chemicals Superfund Site, Brunswick, Georgia (Draft)*
3. *June 20, 2013 Letter From Galo Jackson, USEPA to Prashant Guta, Honeywell, Subject: Comments on the Draft Feasibility Study Report for the Estuary, Operable Unit One*
4. *February 2013 Remedial Investigation Report Operable Unit 3 - Upland Soils, LCP Chemicals Site, Brunswick, Georgia (FINAL)*

5. *October 2012 Remedial Investigation Report Operable Unit One - Estuary LCP Chemicals Site, Brunswick, Georgia (FINAL)*



ENVIRON / ANCHOR QEA	Site Location Map	Figure 2-1
	LCP CHEMICAL SITE, BRUNSWICK, GEORGIA	

Legend

- Gibson Creek
- Approximate Turtle River Estuary
- Purvis Creek
- OU1 Boundary
- Estimated Fishable Area Outside OU1

The Estimated Fishable Area is approximately 5,700 acres

The LCP Estuary is 760 acres.

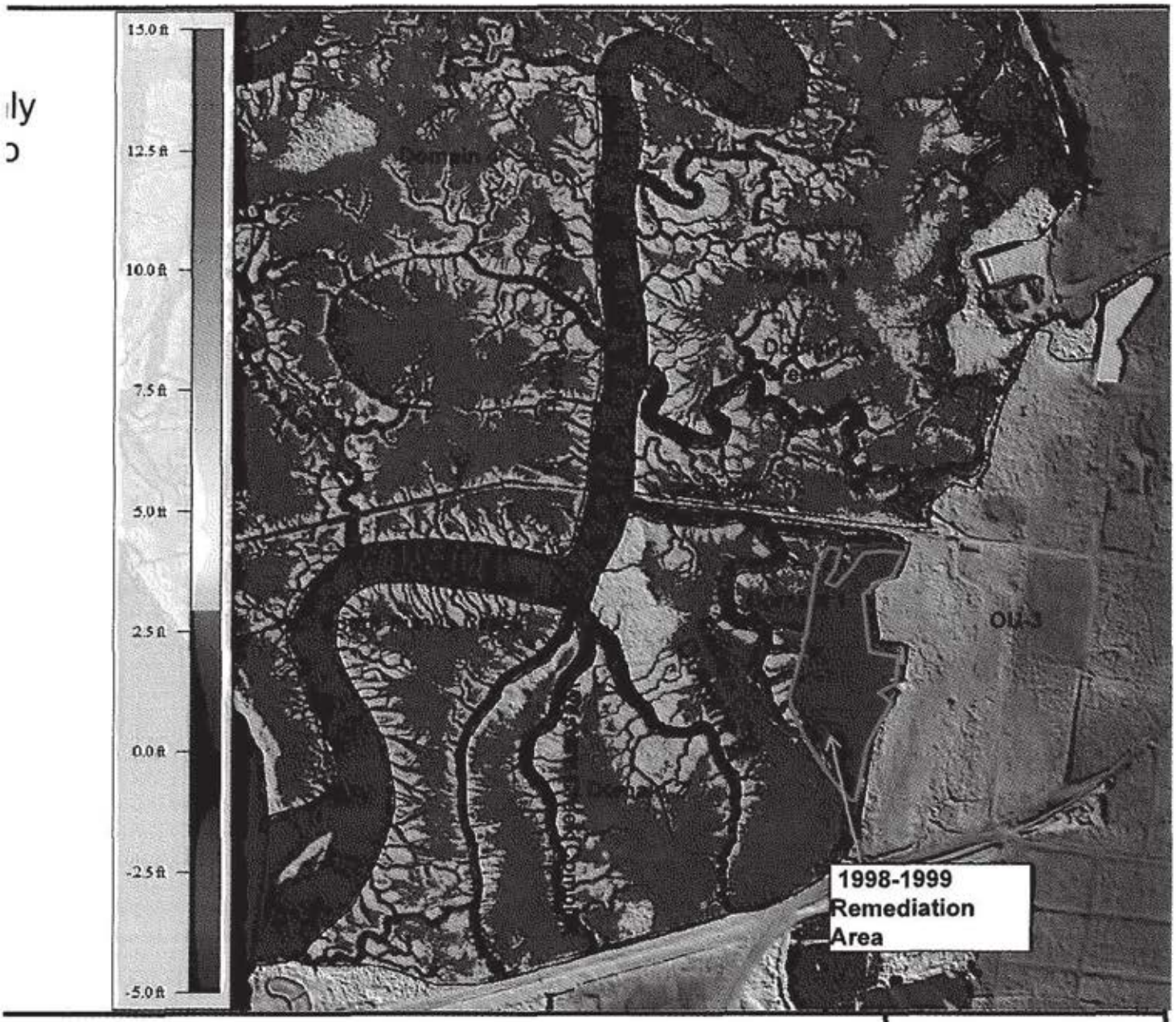
Turtle River Estuary is approximately 19,000 acres.

OU1 Boundary Source: Glynn County LiDAR Data, 2007.

Turtle River/Brunswick Estuary

Figure 2-5

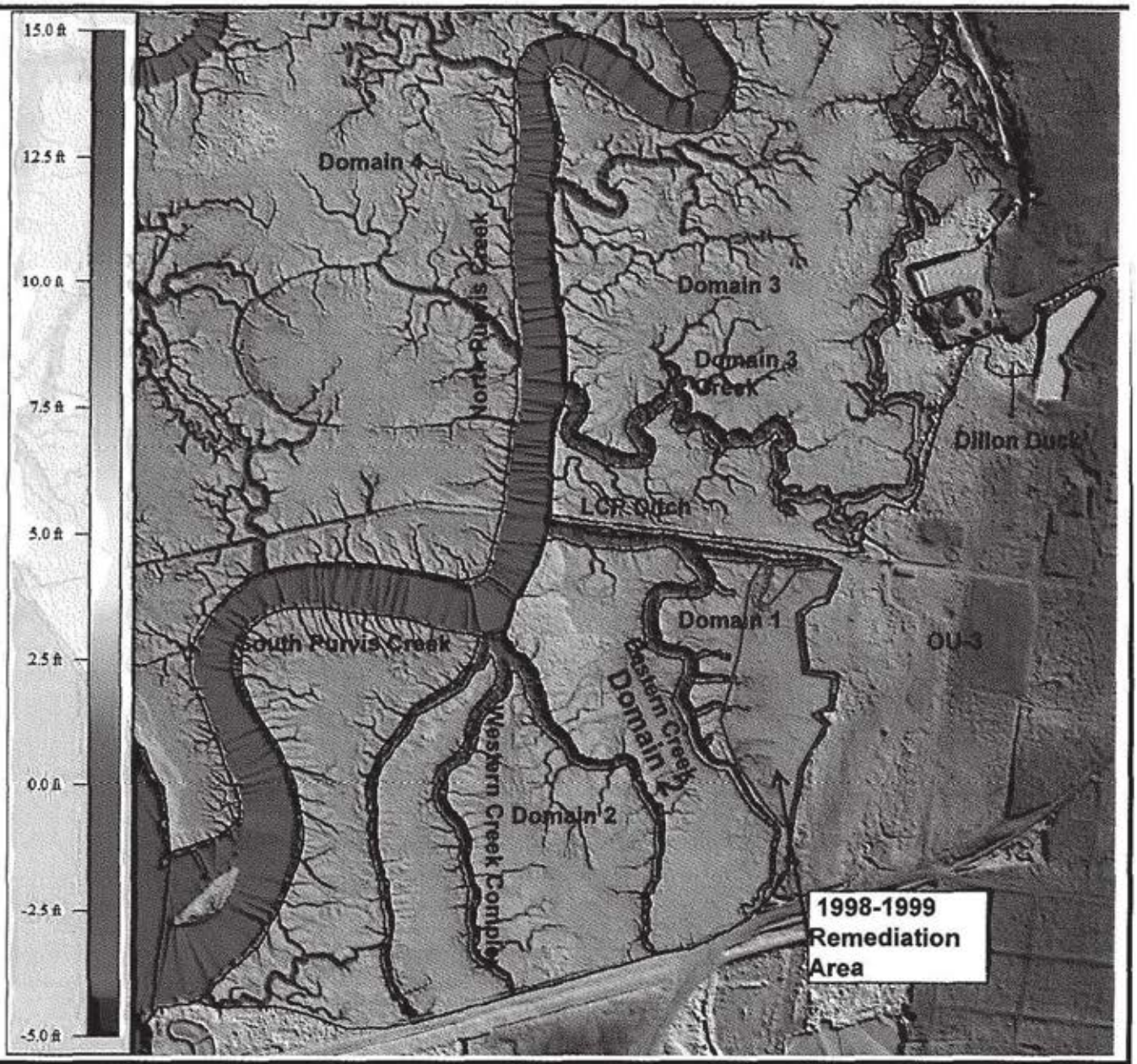
LCP CHEMICAL SITE, BRUNSWICK, GEORGIA



Marsh Inundation – Mean High High Water

LCP CHEMICAL SITE, BRUNSWICK, GEORGIA

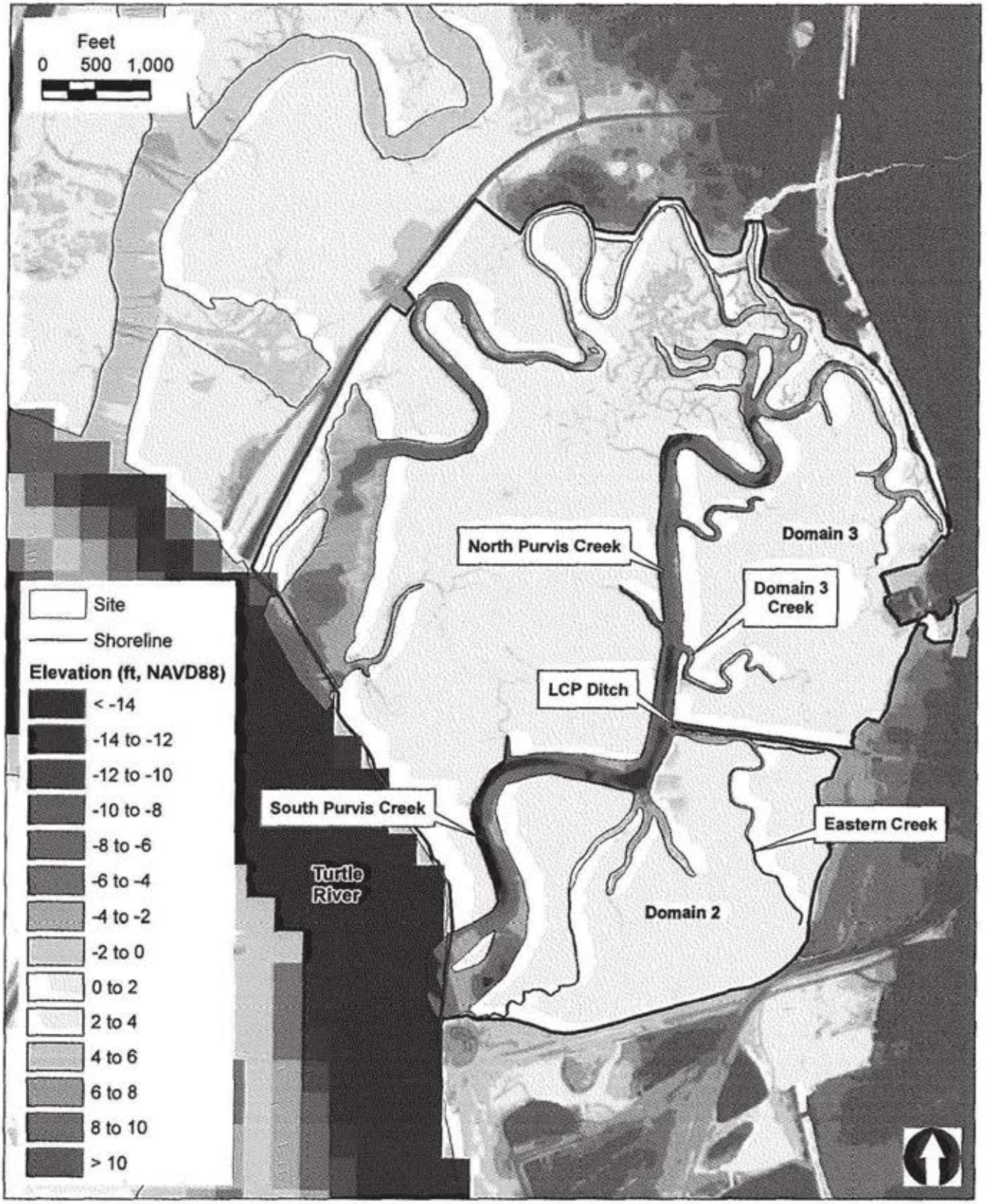
Figure
2-7



Marsh Inundation – Mean Low Low Water

LCP CHEMICAL SITE, BRUNSWICK, GEORGIA

Figure 2-8



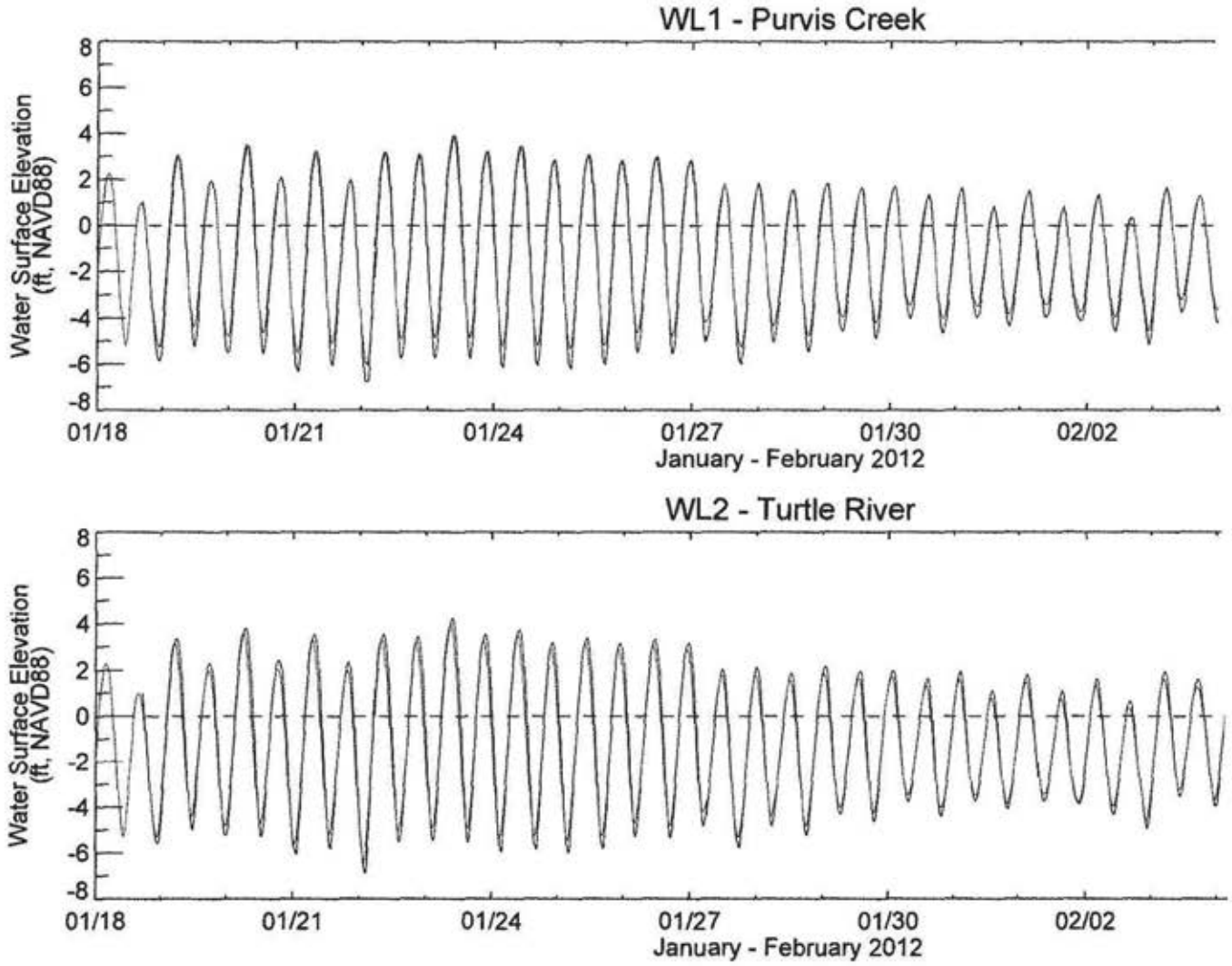
ENVIRON
ANCHOR QEA

Surface Elevation within the Site based on LiDAR Data in Marshes and Single-beam Bathymetry in Channels

LCP CHEMICAL SITE, BRUNSWICK, GEORGIA

Figure B2-4

\\montrivelebu\jobs26st\Jobs\Brunswick\REPORT\HYDRO\120620\Deckstbed_elevation.mxd vlist 9/27/2013 2:09:48 PM

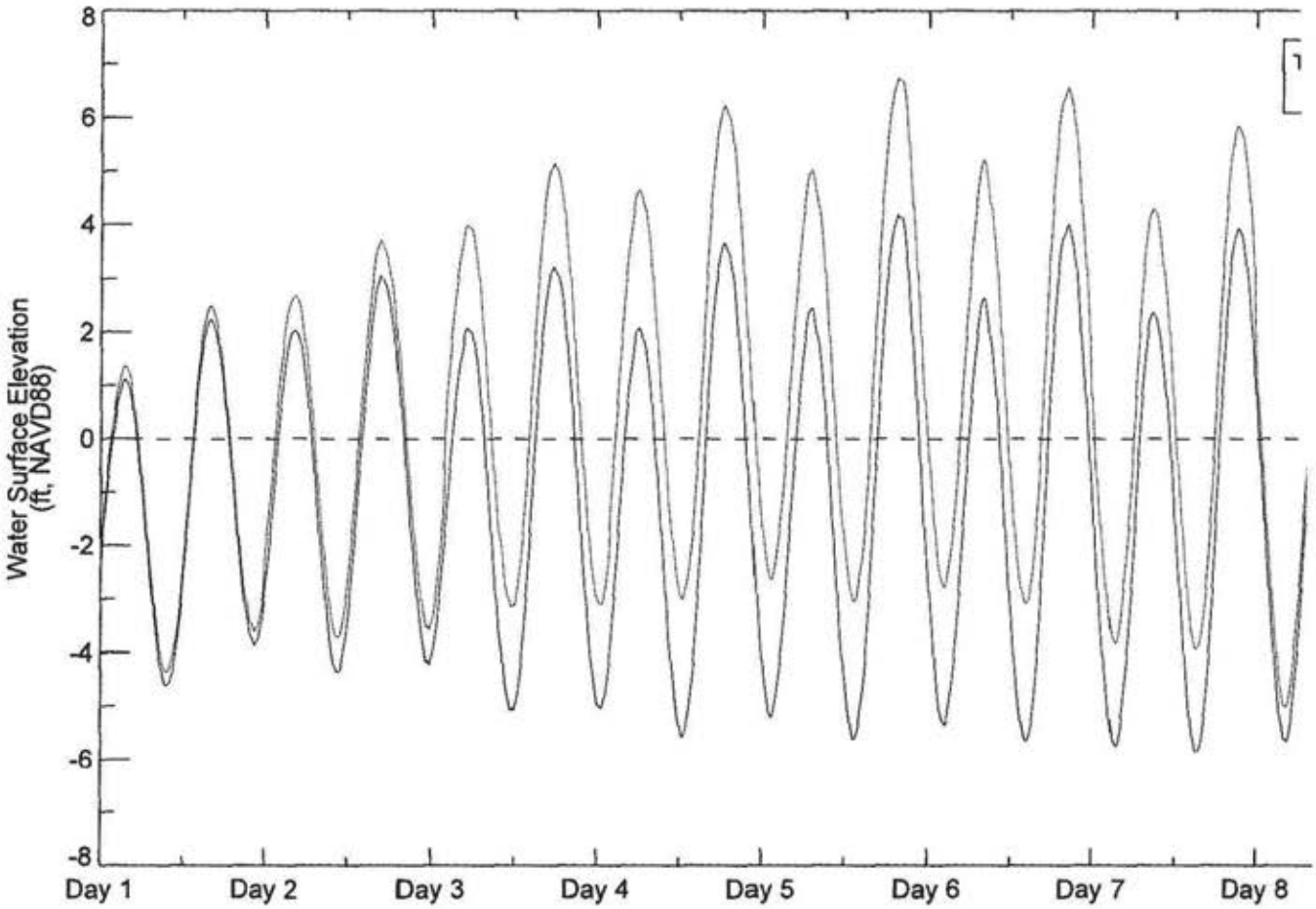


ENVIRON

ANCHOR QEA

Comparison of Predicted and Measured Water Surface Elevation at Stations WL1 and WL2

LCP CHEMICAL SITE, BRUNSWICK, GEORGIA



ENVIRON

ANCHOR QEA

Water Surface Elevation at Downstream Boundary during Hurricane Storm Surge Simulation

LCP CHEMICAL SITE, BRUNSWICK, GEORGIA

Legend

- ● Exceeds Benthic Community RGOs Shown Below
- ○ No Exceedance of Benthic Community RGOs Shown Below
- Remediation Area (48 acres)
- Excluded Area (33 acres)
- OU1 Boundary
- Creek/Domain Boundary
- OU3 Boundary

Constituent	SWAC RGOs	Benthic Community RGOs
Hg	1	4
Ar1268	2	6
Pb	--	90
TPAHs	--	4

Notes:
- Units for all RGOs is mg/kg.

N

0 800 1,600
Feet

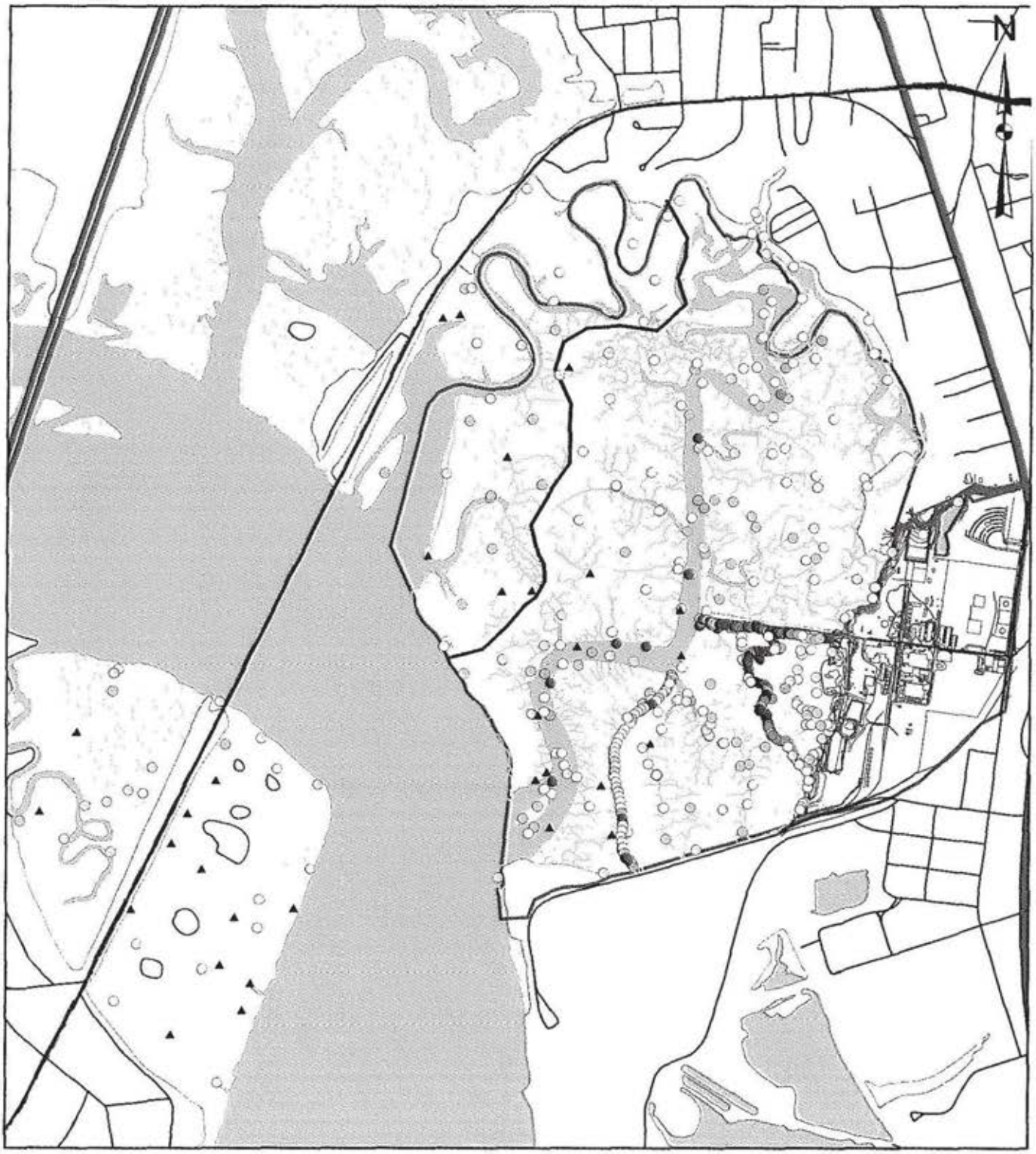
OU1 Boundary Source: Glynn County LiDAR Data, 2007.

ıent Management Area 1

ICAL SITE, BRUNSWICK, GEORGIA

Figure 5-2

Spatial Distribution and Concentration of Aroclor-1268 in LCP Marsh Sediment



Environmental Planning Specialists, Inc.

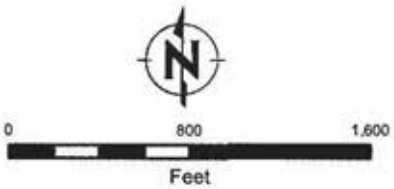
Figure 6-1C

Legend

- No Exceedance of Either Lower or Upper End Benthic RGOs
- Within the Range of Benthic Community RGOs
- Exceeds Range of Benthic Community RGOs
- No Sample Location in 50-Meter Averaging Polygon
- Does not Exceed the Range of the Benthic Community RGOs Shown Below
- Within the Range of the Benthic Community RGOs Shown Below
- Exceeds the Range of the Benthic Community RGOs Shown Below
- OU1 Boundary
- Creek/Domain Boundary
- OU3 Boundary

Constituent	SWAC RGOs	Benthic Community RGOs
Hg	1-2	4-11
Ar1268	2-4	6-16
Pb	--	90-177
TPAHs	--	4

Notes:
-Colored boxes in Purvis Creek and Western Creek Complex reflect locations where averaging along approximately 50-meter polygons was conducted when more than one sample was collected within the approximate 50-meter interval.
-Units for all RGOs is mg/kg.



OU1 Boundary Source: Glynn County LiDAR Data, 2007.

deration for Alternative 1

JNSWICK, GEORGIA

Figure 6-5

February 2013

Philip B. Bedient, Ph.D., P.E.
Curriculum Vitae

ADDRESS:

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Department of Civil and Environmental Engineering
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Email – bedient@rice.edu

P.B. Bedient and Associates, Inc.
13910 Wilde Forest Court
Sugar Land, TX 77498
(281) 491-3911

EDUCATION:

B.S. Physics, University of Florida, Gainesville, Florida, 1969
M.S. Environmental Engineering, University of Florida, 1972
Ph.D. Environmental Engineering Sciences, University of Florida, 1975

PROFESSIONAL EXPERIENCE:

Herman Brown Professor of Engineering - Civil and Environmental Engineering- Rice University - July 2001 to present.
Professor - Environmental Engineering - Rice University - 1986 to 2001.
Professor and Chair - Department of Environmental Science and Engineering, Rice University, Houston, Texas, 1992 - 1999.
Associate Professor - Environmental Engineering – 1980 - 1986.
Assistant Professor - Environmental Engineering – 1975 - 1980.

SCIENTIFIC SOCIETIES:

American Society of Civil Engineers
American Institute of Hydrology
American Water Resources Association
Association of Environmental Engineering Professors
American Academy of Water Resources Engineers
American Geophysical Union

HONORS:

Diplomate - Water Resources Engineer, American Academy of Water Resources Engineers (2008)
C.V. Theis Award from the American Institute of Hydrology (April 2007)
Fellow – American Society of Civil Engineers (April, 2006)
Endowed Chair – Herman Brown Professor in Engineering (July, 2001)
Shell Distinguished Chair in Environmental Science (1988-93)
Phi Beta Kappa

PROFESSIONAL COMMITTEES:

SSPEED Center Committee 2007-2012
Expert Panel – "Impacts of Climate Change on Transportation Systems and Infrastructure in the Gulf Coast" USDOT and USGS, 2005 - 2006
TS Allison Recovery Project - Technical Advisory Committee - 2002-2003
Harris County Flood Control District - Brays Bayou Federal Project Com – 1998- 2002

National Academy of Engineers (National Research Council)
Committee on DoE Environmental Management Technologies (CEMT) - 1995-96
Committee on In-Situ Bioremediation - 1992-93

UNIVERSITY COMMITTEES:

Undergraduate Curriculum Committee, 2005-2012
Accreditation (ABET/SACS) Committee, 2005-2012
Events and Reception Committee (Chair) 2012
Mentorship Committee 2012
Space Planning Committee, 2005-2012
CEE Student-Group Advisors 2012
BSCE Advisor 2012
Center for Civic Engagement Committee, 2007-2012
Parking Committee, 1998-2012
Search Committee, Civil and Environmental Engineering, (2001-2002)
Chair, Dean of Engineering Search Committee, (1988)
Computer Committee, Athletics Committee, 1998-2000
Advisory Council, School of Engineering.

LICENSES:

Professional Engineer, State of Texas, Environmental Engineering (45626)
Professional Hydrologist, American Institute of Hydrology

RESEARCH INTERESTS:

Floodplain Management - Analysis of effects of land use changes and development patterns on flood hydrographs and floodplain boundaries; use of lumped and distributed hydrologic models; detailed modeling of alternative flood control strategies and dynamic floodplain models. Analysis of the severe storm impacts in urban watershed areas using radar rainfall data, combined with GIS techniques for digital terrain and hydraulic modeling in Houston and other coastal areas in Texas.

Flood Alert Systems with Radar - The development of a real-time flood ALERT system (FAS) for Brays Bayou and the Texas Medical Center in Houston, TX has been completed. The FAS currently uses NEXRAD radar for application to flood prediction and real-time flood alert systems. FAS2 is a second-generation system being implemented with funding from FEMA after TS Allison. TXDOT funded a new FAS for inundated bridge crossings (2008).

Groundwater Contaminant Transport - Monitoring and modeling of groundwater hydrology and contaminant movement from various waste sources, numerical and analytical methods for transport with biodegradation. Development and application of tracer studies and models for groundwater transport with biodegradation in a controlled release tank (ECRS), for studying degradation of PCE and TCE plumes and for ethanol in fuel spills. Analysis of plume dynamics at sites in California, Texas and Florida.

Hazardous Waste Site Evaluation - Monitoring and modeling of waste plumes associated with 35 hazardous waste sites nationally. Identification of extent of contamination, transport mechanisms, and control strategies. MODFLOW and RT3D modeling of transport and aquifer restoration using withdrawal-treatment and microbial degradation methods. Analysis of hazardous waste sites in California, Texas and Florida.

COURSES and STUDENTS:

- CEVE 412 - Hydrology and Watershed Analysis
- CEVE 512 - Hydrologic Design Laboratory

- CEVE 101 - Fundamentals of Civil and Environmental Engineering
- CEVE 415/515 - Water Resources Planning and Management (50%)

- 13 Ph.D. and 59 M.S. degrees since 1975

RESEARCH STATEMENT:

Dr. Philip B. Bedient is also Herman Brown Professor of Engineering in the Dept of Civil and Environmental Engineering at Rice University. He teaches and performs research in surface and ground water hydrology, disaster management, and flood prediction systems. He served as Chair of Environmental Engineering from 1992 to 1999. He has directed 60 research projects over the past 38 years, worth of $15 million in research, and has written over 180 articles in journals and conference proceedings. He is lead author on a text on "Hydrology and Floodplain Analysis" (Prentice Hall, 5th ed., 2012) used in over 75 universities across the U.S. He also has a second text on "Groundwater Contamination: Transport and Remediation" (Prentice Hall, 2nd ed., 1999). Dr. Bedient received the Herman Brown endowed Chair of Engineering in 2002 at Rice University. He was elected to Fellow ASCE in 2006 and received the prestigious C.V. Theis Award (groundwater) from the American Institute of Hydrology in 2007. He earlier received the Shell Distinguished Chair in Environmental Science (1988 to 1993) for his work on biodegradation modeling of fuel spills.

He has worked groundwater problems for over 38 years including over 30 major hazardous waste sites and four military bases in Texas, Florida, Utah, Michigan, California, and Louisiana. He has been actively involved in the area of hydrologic transport and groundwater remediation, and developed the original EPA Bioplume Model used for many years to evaluate BTEX plume behavior. He was PI on the Hill Air Force Base Advanced Remediation Study of DNAPL contamination from 1994 – 1999.

He is the current director of the Severe Storm Prediction Center (SSPEED) at Rice University (since 2007) consisting of a team of seven universities and 15 investigators from Gulf coast universities dedicated to improving storm prediction, education, and evacuation from disaster. The Center was approved by the Texas Legislature and is currently funded at over $4.5 million for 5 years from various sources including the Houston Endowment (Hurricane Ike Lessons Learned and Future Steps). A book has been developed and published by TAMU press titled "Lessons from Hurricane Ike" published in June 2012.

Dr. Bedient has over 37 years of experience working on flood and flood prediction problems in the U.S. He has evaluated flood issues in Texas, California, Florida, Louisiana, and Tennessee. He has worked on some of the largest and most devastating floods to hit the U.S. including the San Jacinto River flood of 1994, T.S. Frances in 1998, T.S. Allison in 2001, Hurricane Katrina in 2005, Hurricane Rita in 2005, Hurricane Ike in 2008, and the Nashville, TN flood of 2010. He routinely runs computer models such as HEC-HMS, HEC-RAS, SWMM, and VFLO for advanced hydrologic analysis. He developed one of the first radar based rainfall flood alert systems (FAS-3) in the U.S. for the Texas Medical Center.

The SSPEED Center has put on a number of conferences, meetings, and training courses since 2007. Prominent national speakers have been invited to these conferences, which include attendees from academia, industry, consulting, and emergency managers. These conferences provide a forum for public discussion and response for decision and policy makers, and stakeholders. As a result of this work, we have received a large number of Rice News stories over the past several years, in the form of both video interviews with the media as well as newspaper coverage.

Dr. Bedient has been involved in the technology transfer area for more than three decades through the teaching of short courses for government, university, and private sectors in both groundwater contamination and surface water modeling and prediction.

SURFACE WATER PROJECT

"SSPEED Center Proposal to the Houston Endowment Coastal Integrated Program", Houston Endowment, 2011-2014, $3,200,000.

"FAS3- Operational Support", Texas Medical Center, 2012, $69,000

"Urban Resilience: Flooding in the Houston-Galveston Area", Kinder. 2009-2012, $24,003

"White Oak Bayou BMP Demonstration Project – Cottage Grove Subdivision", City of Houston, 2009-2013, $165,000.

"Rice University FEMA: Food Analysis", Rice, 2011-2012, $70,000

"Amendment to Expand Development and Validation of the Online Storm Risk Calculator Tool for Public Usage", City of Houston, 2011, $388,030

"Hurricane Ike: Lessons Learned and Steps to the Future", Houston Endowment, 2009-2012, $1,250,000

"Libya AEL Training Grant", AECOM, 2008-2010, $1.7 million over 2 years.

"Texas OEM SSPEED Training" University of Texas, 2008, $90,000

"Watershed Information Sensing and Evaluation System", Houston Endowment (with UH), 2007-2010, $400,000.

"Advanced Flood Alert System for the TXDOT for Bridge Control at 288", HGAC, 2007-2011 $200,000.

"Civil and Environmental Engineering for the 21st Century", NSF Dept Reform Grant, 2005-2007, $100,000.

"CASA – Collaborative Adaptive Sensing of the Atmosphere – the Houston Testbed", NSF, 2003 – 2009, $110,000, ($90,000 for 2006-07).

"FAS2 - Operational Support", Texas Medical Center, 2003-2012, $69,000

"Flood Alert System (FAS2) for the Texas Medical Center and Brays Bayou", FEMA, 2002-2003, $300,000.

"Multi-Purpose Water Management Technology for the Texas Mexico Border", Advanced Technology Program, 2000-2001, $129,000.

"Analysis of Clear Creek Watershed," Galveston Bay Preservation Foundation, 1999-2000, $15,000.

"Flood Alert System - Maintenance and Support", Texas Medical Center, 1998-2002, $271,000.

"Flood Prediction System for the Texas Medical Center", Texas Medical Center, 1997-1998, $262,000.

"The Effects of Changing Water Quality and Market Inefficiencies on Water Resource Allocation in the Lower Rio Grande Valley", Energy and Environmental Systems Institute, Rice University, 1996-1997, $12,000.

"Characterization of Laguna Madre Contaminated Sediments", Environmental Protection Agency, 1995, $68,500.

"Role of Particles in Mobilizing Hazardous Chemicals in Urban Runoff", Environmental Protection Agency, 1992-95, $240,000. (P. B. Bedient, Co-P.I.).

"Galveston Bay Characterization Report", Galveston Bay National Estuary Program, 1991-1992, $35,000.

"Characterization of Non-Point Sources and Loadings to Galveston Bay", Galveston Bay National Estuary Program, 1990-1991, $125,000.

"Linkages between Sewage Treatment Plant Discharges, Lake Houston Water Quality, and Potable Water Supply during Storm Events", City of Houston, 1984-1985, $42,200.

"Plan of Study for Upper Watershed Drainage Improvements and Flood Control - San Jacinto River Basin", subcontract from R. Wayne Smith, Engineer, 1984-85, $120,260.

"Harris Gully Sub watershed Study", South Main Center Association, 1983-1984. $15,000.

"Sedimentation and Nonpoint Source Study of Lake Houston", Houston-Galveston Area Council, 1981-1982, $55,000.

"Environmental Study of the Lake Houston Watershed - Phase II", Houston-Galveston Area Council, 1980-1981, $30,000.

"Evaluation of Effects of Storm water Detention in Urban Areas", matching grant with City of Houston Health Department, Office of Water Research and Technology (OWRT), Washington, D.C., and City of Houston Public Health Engineering, 1980-81, $116,000.

"Environmental Management of the Lake Houston Watershed", Funded by City of Houston, Dept. of Public Health, 1978-80, $80,000.

"A Preliminary Feasibility Report for Bear Creek, Texas, Local Protection Project", Grant to Southwest Center for Urban Research, Funded by U.S. Army Corps of Engineers, 1977-78, $47,000.

"Environmental Study of New Iberia Navigation Port and Channel, Louisiana", Funded to Rice Center, 1979, $50,000.

"Strategies for Flood Control on Cypress Creek, Texas", Funded by U.S. Corps of Engineers, Galveston, Texas, 1977, $9,500.

"Water Quality Automatic Monitoring and Data Management Information System", Funded by City of Houston, Dept. of Public Health, 1977-1978, $62,414.

"Maximum Utilization of Water Resources in a Planned Community", The Woodlands Project, 1975-1976.

GROUNDWATER PROJECTS

"A Large-Scale Experimental Investigation of the Impact of Ethanol on Groundwater Contamination", (P.J.J. Alvarez – Co-P.I.) American Petroleum Institute, 2004-2007, $120,000.

"A Large-Scale Experimental Investigation of the Impact of Ethanol on Groundwater Contamination", Gulf Coast Hazardous Substances Research Center, 2004-2005, $45,000.

"A Large-Scale Experimental Investigation of the Impact of Ethanol on Groundwater Contamination", Gulf Coast Hazardous Substances Research Center, 2003-2004, $95,000.

"Chlorinated Solvent Impact and Remediation strategies in the Dry Cleaning Industry", Gulf Coast Hazardous Substances Research Center, 2000 – 2003, $149,400.

"Design Manual for the Extraction of Contaminants from Subsurface Environments", Environmental Protection Agency, 1994-2002, $4,500,000.

"Development of Data Evaluation/Decision Support System for Bioremediation of Subsurface Contamination", Environmental Protection Agency, 1993-1996, $450,000.

Shell Distinguished Chair in Environmental Science, Shell Oil Company Foundation, 1988-1993, $750,000.

"Evaluation of Nitrate-Based Bioremediation: Eglin Air Force Base", Environmental Protection Agency, 1992-1993, $120,000.

"Decision Support System for Evaluating Remediation Performance with Interactive Pump-and-Treat Simulator", Environmental Protection Agency, 1992-1994, $250,000.

"Characterization of Oil and Gas Waste Disposal Practices and Assessment of Treatment Costs", Department of Energy, 1992-94, $200,000.

"Subsurface Monitoring Data for Assessing In-Situ Biodegradation of Aromatic Hydrocarbons (BTEX) in Groundwater", American Petroleum Institute, 1991-93, $170,000.

"System 9 GIS System", Prime Computers, 1989-90, $50,000.

"Effects of Various Pumping and Injection Schemes and Variable Source Loading on Biorestoration", American Petroleum Institute, 1988-90, $186,000.

"Parameter Estimation System for Aquifer Restoration Model", U.S. Environmental Protection Agency, 1987-89, $400,000.

"Distribution of BIOPLUME II", National Center for Ground Water Research (EPA), 1987-88, $40,000.

"Development and Application of a Groundwater Modeling Data Base for Hazardous Waste Regulation", American Petroleum Institute, 1987-88, $40,000.

"Practical Procedures for Evaluating Attenuation of Ground Water Contaminants Due to Biotransformation Process", National Center for Ground Water Research (EPA), 1986-87, $150,000.

"Modeling and Field Testing of Contaminant Transport with Biodegradation and Enhanced In Situ Biochemical Reclamation", National Center for Ground Water Research (EPA), 1985-88, $249,000.

"Ground Water Modeling for the Houston Water Plant", City of Houston, subcontract from Law Engineering & Testing Co., 1985-86, $127,000.

"Environmental Fate and Attenuation of Gasoline Components in the Subsurface", American Petroleum Institute, 1984-86, $78,300.

"Simulation of Contaminant Transport Influenced by Oxygen Limited Biodegradation", National Center for Ground Water Research (EPA), 1984-85, $25,500.

"Ground Water Pollutant Transport along Flow Lines for Hazardous Waste Sites", National Center for Ground Water Research (EPA), 1983-85, $167,000.

"Math Models for Transport and Transformation of Chemical Substances in the Subsurface", National Center for Ground Water Research (EPA), Subcontract from Oklahoma State University, 1982-83, $15,000.

"Characterization of Ground Water Contamination from Hazardous Waste Sites", National Center for Ground Water Research (EPA), 1982-83, $113,000.

"Characterization of Ground Water Contamination from Hazardous Waste Sites", National Center for Ground Water Research (EPA), 1980-82, $45,000.

PUBLICATIONS AND PRESENTATIONS

A. Books or Related Chapters

1. Bedient, P. B. and W. C. Huber, 2012, "Hydrology and Floodplain Analysis", 5th Ed. Prentice-Hall Publishing Co., Upper Saddle River, NJ, February, 2012, 800 page textbook.

2. Bedient, P. B. and J. Blackburn, 2012 "Lessons learned from Hurricane Ike" Ed. Philip Bedient. College Station, TX: Texas A&M University Press, College Station, TX: 2012, 194 Pages

3. Rifai H.S., Borden R.C., Newell C.J. and Bedient P.B., " Modeling Remediation of Chlorinated solvent plumes" In Situ Remediation of Chlorinated solvent Plumes, Chapter 6, H.F. Stroo, C.H. Ward Editors, Springer, N.Y. 2010, 145 pp.

4. Bedient, P. B., Rifai H. S., and Newell C. J., "Ground Water Contamination: Transport and Remediation", 2nd Ed. PTR Publ., Upper Saddle River, NJ, 1999, 605 pages.

5. Thompson, J.F. and Bedient, P.B. "Urban Storm Water Design and Management," The Engineering Handbook, Chapter 94, CRC Press, 2004, 21 pp.

6. Fang, Z., Safiolea, E., Bedient, P.B. (2006) "Enhanced Flood Alert and Control Systems for Houston." In Chapter 16, Coastal Hydrology and Processes, Ed. By Vijay P. Singh and Y. Jun Xu, Water Resource Publications, LLC, pp. 199-210

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8. Horsak, R.D., Bedient, P.B., Thomas, F.B., and Hamilton, C. "Pesticides", Environmental Forensics (2005).

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B.Peer Reviewed Journal Publications

1. Teague, A., J. Christian, and P. Bedient. (2013) "Use of Radar Rainfall in an Application of Distributed Hydrologic Modeling for Cypress Creek Watershed, Texas". Journal of Hydrologic Engineering. DOI: 10.1061/(ASCE)HE.1943-5584.0000567 American Society of Civil Engineers.
2. Doubleday, G., Sebastian A., Luttenschlager, T., and Bedient, B. (2013) Modeling Hydrologic Benefits of Low Impact Development: A Distributed Hydrologic Model of The Woodlands, Texas, Journal of American Water Resources Association
3. Christian, J., A. Teague, L. Duenas-Osario, Z. Fang, and P. Bedient, (2012). "Uncertainty in Floodplain Delineation: Expression of Flood Hazard and Risk in a Gulf Coastal Watershed." Journal of Hydrological Processes, doi:10.1002/hyp.9360.
4. Ray, T., Stepinski, E., Sebastian, A., Bedient, P.B. (2011)"Dynamic Modeling of Storm Surge and Inland Flooding in Texas Coastal Floodplain" ", Journal of Hydrologic Engineering, ASCE, Vol. 137, No.10, October 2011, ISSN 0733-9429/2011/10-1103-1110
5. Fang, Z., Bedient, P. B., and Buzcu-Guven, B. (2011). "Long-Term Performance of a Flood Alert System and Upgrade to FAS3: A Houston Texas Case Study". Journal of Hydrologic Engineering, ASCE Vol. 16, No. 10, October 1, 2011, ISSN 1084-0699/2011/10-818-828.
6. Stepinski, E., J. Christian, and P. Bedient, (2011.) "Methods for Modeling Coastal Floodplains Under Hurricane Storm Surge Conditions." Journal of Hydrological Processes. (Accepted) July 2011
7. Teague, A., Bedient, P. and Guven, B. (2010). "Targeted Application of Seasonal Load Duration Curves using Multivariate Analysis in Two Watersheds Flowing into Lake Houston" (JAWRA-10-0003-P.R1). Journal of American Water Resources Association. Accepted.
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11. Rifai, H.S., Borden, R. C., Newell, C. J., and Bedient, P.B. "Modeling Dissolved Chlorinated Solvents in Groundwater and Their Remediation," in SERDP monograph on Remediation of Dissolved Phase Chlorinated Solvents in Groundwater, (accepted) 2007.
12. Bedient, P. B., Holder, A., and Thompson, J. F., and Fang, Z. (2007). "Modeling of Storm water Response under Large Tailwater Conditions – Case Study for the Texas Medical Center". Journal of Hydrologic Engineering, Vol. 12, No. 3, May 1, 2007.
13. Capiro, N.L., Stafford, B.P., Rixey, W.G., Alvarez, P.J.J. and Bedient, P.B. "Fuel-Grade Ethanol Transport at the Water Table Interface in a Pilot-Scale Experimental Tank" Water Research, 41(3), pp. 656-654, 2007.

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20. Capiro, N.L. and Bedient P.B. "Transport of Reactive Solute in Soil and Groundwater" The Encyclopedia of Water, John Wiley and Sons, Inc., New York, NY, USA pp. 524-531, 2005.

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Conference Proceedings and Other Technical Publications

1. Juan, A., Fang, Z., and Bedient, P. B. (2012). "Flood Warning Indicator: Establish a Reliable Radar-Based Flood Warning System for Sugar Land, Texas", American Geophysical Union (AGU) 2012 Fall Meeting, San Francisco, CA, December 3-7.

2. Deitz, R., Christian, J. K., Wright, G., Fang, Z., and Bedient, P. B. (2012). "Linkage of Rainfall-Runoff and Hurricane Storm Surge in Galveston Bay", American Geophysical Union (AGU) 2012 Fall Meeting, San Francisco, CA, December 3-7.

3. Bedient, P. B., Doubleday, G., Sebastian, A., and Fang, Z. (2012). "Distributed Hydrologic Modeling of LID in the Woodlands, Texas", American Geophysical Union (AGU) 2012 Fall Meeting, San Francisco, CA, December 3-7.

4. Burcham, M. ,Bedient,P., McGuire, T., Adamson, D., . New Ch., (2012) Occurrence of Sustained Treatment Following Enhanced Anaerobic Bioremediation at Chlorinated Solvent Sites□, AGU Fall Meeting, San Francisco, California, December 3-7 2012

5. Fang, Z. and Bedient, P., Performance Evaluation of a NEXRAD-Based Flood Warning during Recent Events in 2012□, AGU Fall Meeting, San Francisco, California, December 3-7 2012

6. Juan, A., Fang, Z. and Bedient, P., Radar-based Flood Warning Indicator for the Upper Oyster Creek Watershed in Sugar Land, Texas□ *AGU* Fall Meeting, San Francisco, California, December 3-7 2012

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Invited Lectures (Recent)

1. The Resilience and Adaptation to Climate Risks Workshop: NASA Johnson Space Center and the Houston/Galveston Area, March 8, 2012, Houston, Texas

2. Bedient, P.B., SSPEED Conference. Chair and Organizer, "*Hurricane Ike, Revisited,*" September 14, 2009, Houston, Texas.

3. Bedient, P.B., SSPEED Conference. Chair and Organizer, "*Severe Storm Prediction and Global Climate Impact in the Gulf Coast,*" Sponsored by American Institute of Hydrology. October 29-31, 2008, Houston, Texas. (Attended by over 150 guests and speakers).

4. Bedient, P.B., SSPEED Conference. Chair and Organizer, "*Severe Storm Prediction and Global Climate Impact in the Gulf Coast,*" Sponsored by American Institute of Hydrology. October 29-31, 2008, Houston, Texas. (Attended by over 150 guests and speakers).

5. Bedient, P.B., Robinson, and H., Fang, Z. (2008). "Distributed Hydrologic Model Development in the Topographically Challenging Yuna River Watershed, Dominican Republic". Meeting in Dominican Republic before the President October 20, 2008.

6. Bedient, P.B. (June, 2008) Plan for the Dominican Republic Flood Study, before the Ministers of Education, Environment, and Economic Development.

7. Bedient, P.B. "Advanced Flood Alert Systems in Texas" International Disaster Response Conference, Daves, Switzerland, August 28, 2006.

8. Bedient, P.B. "IP2 Flood Alert System for Houston" CASA Meeting NSF Review, UMASS. April, 2006.

9. Bedient, P.B. "Severe Storm Impacts in the Gulf Coast" Severe Storm Impacts and Disaster Response in Gulf Coast, Houston, Rice University, March 15-16, 2006.

10. Bedient, P.B. "Living with Severe Storms in the Gulf Coast- Scientia Lecture" Rice University, Houston, TX. (September 2005).

11. Bedient, P.B., Fang, Z., Safiolea, E., and B.E. Vieux "Enhanced Flood Alert System for Houston" 2005 National Hydrologic Council Conference: Flood Warning Systems, Technologies and Preparedness, Sacramento, California. (May 16-20)

12. Fang, Z. and Bedient, P.B. "Enhanced Flood Alert and Control Systems for Houston" Proceedings of the 25th American Institute of Hydrology Conference: Challenges of Coastal Hydrology and Water Quality. Baton Rouge, Louisiana, May 21-24, 2006.

13. Fang, Z., Bedient, P.B., and R. Hovinga "Prediction of Severe Storm Flood Levels for Houston Using Hurricane Induced Storm Surge Models in a GIS Frame" Proceedings of AWRA 2006 Spring Specialty Conference: GIS and Water Resources IV. Houston, Texas, May 8-10, 2006.

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15. Capiro, N.L., Da Silva, M.L.B., Stafford, B.P., Alvarez, P.J.J., and P.B. Bedient "Changes in Microbial Diversity Resulting from a Fuel-Grade Ethanol Spill" Eighth International Symposium on In Situ and On-Site Bioremediation, Baltimore, MD. (June 2005).

16. Safiolea, E. and P. B. Bedient "Assessment of the Relative Hydrologic Effect of Land Use Change and Subsidence Using Distributed Modeling" EWRI Watershed Management Conference, Williamsburg, VA. (July 9-22, 2005)

17. Capiro, N.L., Stafford, B., He, X., Rixey, W.G., and P.B. Bedient "A Large-Scale Experimental Investigation of Ethanol Impacts on Groundwater Contamination" Presentation at the Fourth International Conference on Remediation of Chlorinated and Recalcitrant Compounds; Monterey, CA; May 2004.

18. Capiro, N.L., Da Silva, M.L.B., Stafford, B.P., Alvarez, P.J.J., and P.B. Bedient "Changes in Microbial Diversity Resulting from a Fuel-Grade Ethanol Spill" Accepted for Presentation at The Eighth International Symposium on In Situ and On-Site Bioremediation; Baltimore, MD. June 2005.

19. Safiolea, E. and P.B. Bedient "Analysis of Altered Drainage Patterns and Subsidence Impact Using a Distributed Hydrologic Model" AWRA Annual Water Resources Conference in Orlando FL, November, 2004.

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22. Capiro, N.L., Adamson, D.T., McDade, J.M., Hughes, J.B., and P.B. Bedient "Spatial Variability of Dechlorination Activity Within a PCE DNAPL Source Zone" Presentation The 7th International Symposium In Situ and On-Site Bioremediation; Orlando, FL; June 2003

23. Benavides, J.A. and P.B. Bedient "Improving the Lead-Time and Accuracy of a Flood Alert System in an Urban Watershed" 2003 AWRA Annual Conference, San Diego, California, November 2003.

24. Whitko, A.N. Bedient, P.B., and S. Johnson "Sustainable Flood Control Strategies in the Woodlands – Thirty Years Later" 2003 AWRA Annual Conference, San Diego, California, November 2003.

25. Safiolea E., Hovinga, R., and P.B. Bedient " Impact of Development Patterns on Flooding in Northwest Houston using LIDAR Data" 2003 AWRA Annual Conference, San Diego, California, November 2003

26. Benavides, J.A. and P.B. Bedient "Improving the Performance of a Flood Alert System Designed for a Rapidly Responding Urban Watershed" 2003 Conference on Flood Warning Systems Technologies and Preparedness, Dallas, Texas. October 2003.

27. Bedient, P.B., Holder, A., and Baxter Vieux "A Radar-Based Flood Alert System (FAS) Designed for Houston, TX" *International Conference on Urban Storm Drainage*, Portland, OR, September 2002.

28. Holder, A., Stewart, E., and P.B. Bedient "Modeling an Urban Drainage System with Large Tailwater Effects under Extreme Rainfall Conditions" *International Conference on Urban Storm Drainage*, Portland, OR, September 2002.

29. Glenn, S., Bedient, P.B., and B. Vieux "Analysis of Recharge in Ground Water Using NEXRAD in a GIS Format" *AWRA Summer Specialty Conference*, Keystone, CO, July, 2002.

30. Bedient, P.B. "Flood ALERT System (FAS) for Brays Bayou and the TMC" T.S. Allison: A Brays Bayou Event, Rice University Conference Presentation, November 13, 2001.

31. Bedient, P.B. "Flood ALERT System for the Texas Medical Center" Hurricanes and Industry, Houston Conference Presentation, November 7, 2001.

32. Bedient, P.B. and J.A. Benavides "Analyzing Flood Control Alternatives for the Clear Creek Watershed in a Geographic Information Systems Framework" presented at ASCE's EWRI Spring 2001 World Water & Environmental Resources Congress Conference.

33. Hoblit, B.C., Bedient, P.B., B.E. Vieux, and A. Holder "Urban Hydrologic Forecasting: Application Issues Using WSR-88D Radar" *Proceedings American Society of Civil Engineers Water Research, Planning and Management 2000 Conference,* Minneapolis, MN, August 2000.

34. Spexet, A., Bedient, P.B., and M. Marcon "Biodegradation and DNAPL Issues Associated with Dry Cleaning Sites" *Proc. Natural Attenuation of Chlorinated Solvents, Petroleum and Hydrocarbons Conference,* Bruce Alleman and Andrea Leeson eds., 5(1), pp. 7-11, Battelle Press, Columbus, Ohio, 1999.

ATTACHMENT B

Review of the LCP Chemicals Site, Brunswick, GA.

By Loren H. Raun, Ph.D.

March 13, 2015

Loren H. Raun

P. B. Bedient and Assoc., Inc

Review of the LCP Chemicals Site, Brunswick, GA.

I was retained on this project for the purpose of evaluating the development of the remedial goals proposed for the estuary impacted by the LCP Chemicals Site. My opinions are based on my professional experience in human health risk assessment, environmental science, environmental statistics and hydrogeology and review of relevant data summaries, figures and documentation to date, and are subject to change if and when additional information becomes available.

Section I. Qualifications

My educational background, research and professional experience and the review of documents provided are the basis of my opinions. I hold a Ph.D. degree from Rice University in Houston in Environmental Science and Engineering and a B.S. in geophysics from the University of Texas in Austin, and I have attached a curriculum vita including a list of peer-reviewed publications. I am a research faculty fellow in the Department of Statistics at Rice University, where I have been on faculty since 2003, and teach courses in human health risk assessment and environmental statistics. My research focuses most heavily on tracking health effects from pollution exposure. I have extensive experience as a risk assessment reviewer for state and local governments and have served on EPA Science Advisory Board, Risk and Technology Review Methods Panel.

Section II. Comments on Development of Remedial Goals

The ultimate selection of remedial goals (RGOs) for the estuary and the method to achieve these goals is based on analysis of a complex interaction between the contamination in sediment, surface water, groundwater, soil and human and ecological receptors. Although much data have been collected and sophisticated models used, there is a large degree of uncertainty associated with the RGOs. In the thousands of pages of analysis there are times when conservative assumptions (i.e., which would result in more restrictive RGOs) were applied but there are equally multiple junctures where decisions were made which result in underestimation of risk and RGOs. The overarching concern is that RGOs be protective in spite of the uncertainties and that remediation attains these RGOs in this dynamic environment. In general some factors which could compound to underestimate the RGO or add to the uncertainty in this FS include:

Failing to add risk from OU3 when estimating the RGO for OU1- The contamination has been separated into three operable units (OU) for study and management. These units are the original site (OU3), the groundwater (OU2) and the estuary (OU1). The RGOs for the estuary were developed based on a baseline human health risk assessment and ecological risk assessment. As part of the risk assessment, receptors are identified. An important receptor in the OU1 risk assessment is the high rate consumer of seafood. Important receptors for the OU3 risk assessment are the onsite resident, worker or trespasser. Risk assessment requires that all exposure pathways for a receptor be considered. Clearly, the high rate seafood consumer could also be a resident, worker or trespasser. In other words, the risk for the high rate consumer should be added to the risk of receptors considered in the OU3 risk assessment, and RGOs developed based on the added risk. While it is acceptable to separate the contamination into operable units for management, it is not justifiable to consider the risk in an operable unit in a vacuum.

Failing to add the risk from exposure to surface water or sediment- Within the risk assessment conducted for OU1, risk from human exposure to surface water and sediment were not included in the development of RGOs. The only risk considered was consumption of seafood. Any risk added from these other pathways would result in lower RGOs.

Underestimating consumption of contaminated food by relying on default exposure factors especially given a large portion of the local community is below the poverty level (exposure frequency, ingestion rate), and likely a sensitive subpopulation- The risk assessment relies on default exposure factors to estimate the intake of the seafood for the high rate consumer. A better understanding of the local consumption pattern is extremely important to correctly calculate the risk from seafood ingestion. With a high percentage of individuals and families below the poverty level, the community may be relying heavily on seafood for meals. It is conceivable that more than one meal a day is seafood. The exposure frequency could easily be underestimated. The intake rate (the amount of seafood eaten per meal) used in the risk assessment may also be underestimated. The relationship between income and weight (and presumably intake) can vary by gender, race-ethnicity and age. Increase in intake or exposure frequency will add risk for the consumption of seafood and result in lower RGOs.

Misrepresenting concentration levels by not including statistical confidence- Samples are taken to estimate concentrations of the true population parameters (e.g., mean) in a media or seafood. While the true population parameter is not known, we can identify an interval within which we are statistically confident the parameter may fall. It is never appropriate to assume the sample average is the true mean, instead the upper or lower limit of the confidence limit is used. The sample average is used repeatedly in the FS to represent the true mean and no confidence intervals are presented. This adds to the uncertainty in the RGOs, depending upon where it is applied it will raise or lower the RGOS.

Basing decisions on small sample sizes without enough statistical power. Samples are taken in a media and compared to a threshold (standard) or concentrations from a previous year. It is not appropriate to compare a sample average to limits or other distributions directly. The comparison must consider the variability of the data (see previous comment) and the statistical power. The statistical power is a measure of whether enough samples were collected to be able to detect a difference between the concentrations and the threshold if one existed. All other factors being equal, more samples are required for highly variable data than lower variable data. Power is never discussed in this FS.

Misrepresenting decreases in concentration which are not statistically significant. Environmental data vary in time for many reasons. The determination of if a concentration is decreasing in a media is conducted with a statistical trend test. It is not appropriate or sound science to present a graph or concentrations and state they are decreasing without discussing if the decrease is statistically significant.

Screening out COCs which did not exceed screening levels/standards or were present in the background. When chemicals of concern are screened out of the risk assessment because they were below a standard or were present in the background, an analysis of the impact on the RGOs if they had been included in the risk assessment is appropriate in an uncertainty analysis. The polycyclic aromatic hydrocarbons found at the site are also found in the background, however they do pose an involuntary risk to the community from the environment and therefore should be consider in some manner. The COCs below a surface water screening level or sediment screening level could contribute risk and impact the RGOs,

especially for example, if screening levels were developed assuming 1x10-5 risk as an acceptable limit.

In general some factors which would interfere with the attainment of the RGO include:

- Discharge from groundwater to the estuary; no explanation is provided for why the remediated area has increased in concentration
- Use of the sample arithmetic average to calculate the RGO when this value should be used to estimate the limits of the true mean and should be evaluated using a method consistent with the underlying distribution of the data
- Selection of 50 foot grid cell averages which dilute the cell average
- Comparison of average to limit without incorporating statistical confidence (as discussed previously)

Specific discussion of all of these general uncertainties is not feasible given the extent of the analysis. However, specific discussion with respect to some aspects of the uncertainties are included below.

Specific Comments

Groundwater- Groundwater was not included in the risk assessment or evaluation of the remedy although it is heavily contaminated and in contact with the surface water. The report indicates that seeps directly along the formerly remediated area and up gradient of Eastern Creek do discharge contaminated groundwater, however, modeling indicates surface water dilution would make the contribution negligible. There are several concerns associated with this conclusion.

It is apparent that sediment contamination exists around the area remediated in 1999. It is possible that this is empirical evidence that the seeps are recontaminating the formerly remediated area and therefore, groundwater is in fact acting as a continuous source. The report uses a simple mass flux calculation to estimate the mass that the groundwater could contribute. The analysis indicated that the concentrations from the groundwater could not account for the concentration now seen in the remediated area. However, there is no explanation given as to how the concentration increased since the remediation. In a situation where a model does not match the measured values, it would be helpful to pinpoint what model input would in fact create

such a concentration. Is it physically possible to re-contaminate from the groundwater to the level found? The model input was conservative but not necessarily correct. There are multiple areas of uncertainty including: the use of some filtered groundwater sample concentrations when unfiltered are more appropriate for the pcbs and mercury (only unfiltered should be use), the gradient from two events (no indication if events reflect high or low conditions), the assumption of homogeneity in the lithology, constant flow direction, variable height of surface water. If the recontamination concentration could not be achieved from the groundwater, is there another source that should be considered such as the OU3 surface soils which are also not included in the evaluation of the estuary. An increase after remediation indicates we do not know the full extent of the current contamination as it is increasing in some locations.

The report then indicates that the concentrations discharged to the surface water from contaminated groundwater would not pose any concern because they would be diluted by the surface water. There are concerns with this analysis also. First, the report has established that the COCs of mercury and PCBs are not found in filtered surface water but in the colloidal suspension or in the sediment. If the groundwater discharges contamination to surface water, the contamination will partition more heavily to the sediment. Dilution will have a limited impact. Dilution assumes something like complete mixing. The report indicates that the area around the upper reaches do not experience inundation and therefore, complete mixing is not expected. Clearly, the Eastern Creek has received the brunt of the contamination. This may be because the location acts as a sink. Complete mixing would not occur in a sink.

There is a discussion of dilution of the seep pore water samples down to insiginificant levels. Groundwater would seep when the hydraulic head in the groundwater is higher than the surface water. Groundwater could reasonably seep into a bank above the water level contaminating the soil and sediment.

The report presents the difference in mercury concentration in surface water when only examining dissolved phase and when examining total. The information presented about the seep sampling does not indicate if the samples were filtered. The results could be highly misleading if the concentrations presented are in fact from filtered samples. Likewise, we do not expect to see PCBs in the dissolved phase but in the colloids in the sample.

The report indicates that the seeps occur where the water bearing sand is exposed along the marsh edges. Does the remedy consider the seeps? Will the seeps be aggravated by the remedy? Should the groundwater be retained near these surfaces, especially in the vicinity of transect 1 where concentrations are highest?

Fish Tissue

Appendix F is first discussed in the FS in terms of decrease in concentration of fish concentration over time. It is referenced in Figure 6-4B. The figure graphically shows the concentration range for striped mullet over time. While the concentrations in 2011 appear lower, and may be lower in reality, there is no statistically significant difference between the 2011 and 2007 concentrations according to this data. There are not enough samples to detect a difference between the concentrations (i.e., not enough statistical power).

This appendix presents a comparison of the change in concentration in seafood over the years from the Turtle River and the associated safe concentration level. The safe concentration intake level (gm/day) related to meals per week, is based on the level associated with the carcinogenic risk (limit = 1x10-4) or non-cancer hazard (limit =1), whichever is more restrictive. The calculation assumes 30 year exposure, 70 kg adult, and 70 year lifetime. There are three main issues which result in bias in the presentation of this data:

<u>Comparison between concentrations in seafood between years does not consider statistical confidence.</u>

The main report indicates that the concentration in seafood has decreased. The text of the FS focuses on the fish advisories showing decreases across years. While the advisories have decreased, this implies that the concentrations in the fish have decreased near the site. The decrease is largely overstated according to the data shown in Figure F-3B. It is not appropriate to compare the sample means or individual levels to benchmarks (as shown in the Figure) without considering the statistical confidence, especially with so few samples (sample size of 1 to 3). Sample sizes this low have very limited statistical power. Limiting this critique to comparisons with at least 3 samples, Figure F-3B data appear to indicate that are there two seafood types with a statistically significant decrease in concentration. Estimating concentrations from the plot of those types of seafood, blue crab and white shrimp may have a

statistically significant decrease while striped mullet, black drum, southern kingfish and spotted seatrout do not. There is uncertainty because of the low sample size, and the lack of use of statistics to provide a quantitative conclusion introduces a sense that the report is not presenting straightforward results but a bias.

Comparison between concentrations in seafood to the advisory threshold does not consider statistical confidence.

In addition, although the same plot implies that the mean of the blue crab was greater than the 1 meal per month limit in 2002 while in 2011 it is below that limit, this implication is not statistically founded. When the concentration of blue crab are statistically compared to the benchmark (95th upper confidence limit of the blue crab), the concentrations are not below the 1 meal per month limit. This analysis of eyeball comparison is unsophisticated and tends toward bias.

Additive Risk not considered

Unfortunately, the seafood advisories appear to consider only one contaminant at a time, when a fish could actually contain both mercury, lead and PCBs. Where the risk may be below a 1 meal per month limit for PCB and mercury individually, the summation may exceed the limit. In addition, a similar scenario of additive risk exceeding a limit could occur if the risk was below the 1 meal per month limit for blue crab and for shrimp but if a receptor ate both, they could be above the limit. The 1 meal per month limit is based on the risk of 1x10-4 per seafood type per chemical. This type of simplification is not protective with multiple contaminants impacting many different types of seafood.

Development of RGOs and Determination of Areas Exceeding RGOs

Appendix G: Letter from EPA to Mr Gupta Re: Human Health Risk Assessment for the Estuary, Operable Unit One (OU 1): LCP Chemicals Superfund Site, Brunswick, Glynn County, Georgia

In development of the RGOs the only pathway that the EPA considers is consumption of fish. The risk from a local resident or trespasser exposure to OU3 or sediments from OU1 should be

added to the ingestion of contaminated food (finfish, clapper rail and shell fish). If the trespasser or resident also ate contaminated food, the carcinogenic risk would increase by as much as 3.3E-6, and 5.2E-5, respectively. These additions would result in a lowering of the sediment RGOs.

Attachment A presents the method to calculate area weighted average. While spatial weighting between the areas is reasonable, use of the average to represent an area is not statistically appropriate. The sample average is only an estimate of the mean concentration and will vary depending upon the number of samples collected. The true mean must be estimated through a confidence interval. The human health risk assessment consistently used the 95th upper confidence limit of the mean with reference to EPA guidance requiring this. However there is not parity in the use of statistics or the sophistication of the statistics used in the FS or in the ecological risk assessment. Statistical confidence should be considered in the calculation in Attachment A. There is not enough information provided to determine if the underlying distribution of the data are normal. The data are likely not normal and contain high concentration outliers therefore, more sophisticated statistical methods should be employed within each area.

In the case of calculating the RGO, the *lower confidence limit* should be used. The outliers would have biased the spatial weighted area arithmetic averages high. The assumption of the Attachment is that fish body burden is related to the sediment. The sediment remedial goal was calculated as the sediment concentration divided by the hazard index or risk. Therefore, if the value used to represent the concentration is higher than it should be (e.g., the skewed arithmetic average instead of the lower confidence limit of the mean), the RGOs will be higher than they should be.

For example, the RGO for the clapper rail is currently:

Target tissue at 1e-4 risk: 19.42/1.54e-4= x/1e-4, I x=12.95

Sed RGO: 19.42/3.408 mg/kg average=12.95/x, x=2.3

If the concentration was lower than 3.408 by 1 mg/kg (which it could easily be given the range of concentrations), then the RGO would be 1.6 mg/kg instead of 2.3 mg/kg. The BAF approach is also dependent on the sediment concentration and would be equally impacted.

Identification of areas exceeding RGOs was also based on arithmetic average without consideration for statistical confidence in some location.

Cost of Remediation/Selection of Remedy

The restrictions on fishing, the potential health consequences due to exposure and the stress of living in or near a contaminated area have inflicted a burden on the local community. According to the census, this community is largely African American and between a quarter to just under a third of the population live below the poverty level. The cost associated with this burden is not considered in the remedy evaluation. Fishing advisories will not keep hungry community members from eating contaminated seafood. The cost savings from avoiding adverse health should be considered. Choosing a remedy which will provide the fastest route to safe levels with limited uncertainty should be the main objective. The most reliable remedy is removal. Considering the uncertainty in this assessment, the more protective RGOs should be applied.

The report indicates that the dredging would be more damaging to the habitat than other remedial measures, however, the previously remediated area recovered much sooner than anticipated (two years). In addition, the contamination is on the surface of the sediment, not at depth. Therefore, the contaminants should be removed and the marsh replanted in the same manner as the previously remediated area.

Section III. Documents Reviewed

1. *April, 2011 Baseline Ecological Risk Assessment for the Estuary at the LCP Chemical Site in Brunswick, Georgia, Site Investigation/Analysis and Risk Characterization (Revision 4)*

2. *April, 2011 Human Health Baseline Risk Assessment for the Estuary, Operable Unit 1, Marsh Trespasser, Fish and Shellfish Consumer, Clapper Rail Consumer, Final, LCP Chemicals Superfund Site, Brunswick, Georgia*

3. *January 2012 Human Health Risk Assessment for Upland Soils (Operable Unit 3) LCP Chemicals Site, Brunswick, Georgia*

4. *June 2, 2014 Draft Feasibility Study, Operable Unit No. 1 (Estuary), LCP Chemicals Superfund Site, Brunswick, Georgia (Draft)*

Curriculum Vitae

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Senior Environmental Analyst
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Houston, TX
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Faculty Research Fellow and Lecturer
Department of Statistics
Rice University
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Education

1998 Ph.D., Environmental Science and Engineering
Rice University
Thesis research: Statistical Investigation of Air Pollution, Human Exposure Assessment; empirical modeling of ozone monitoring data using 3-D kriging, correlated to personal monitoring and exposure, asthma incidence and decrease in lung function in children and athletes

1989 M.S., Environmental Science and Engineering
Rice University
Thesis research: Groundwater Pollution, Stochastic Groundwater Fate and Transport Modeling; developed probabilistic input distributions for groundwater transport parameters for a range of hydrogeologic environments and lithologies and evaluated EPA Land ban model EPACML, (Monte Carlo)

1986 B.S., Geophysics
University of Texas, Austin, Texas

Academic Experience

2003-present Faculty, Rice University, Statistics Department, environmental statistics and human health risk assessment. These are graduate classes in a lecture/project format. The environmental statistics class focuses on using statistical tools to assess current environmental contaminant data. Topics include: sampling decision, distributional assessment,

hypothesis testing (parametric and nonparametric), trend analysis and comparison tests to evaluate human health thresholds. The human health risk assessment class focuses on all aspects of environmental contaminant risk assessment and includes exposure and contaminant transport modeling. Positions held: Faculty Fellow (2011 to present), Lecturer (2008-2010 and 1999-2001).

1999 — Lecturer, University of Houston, Civil and Environmental Engineer Department, graduate air pollution transport. This is a graduate air pollution transport and modeling class.

Other Research and Work Experience

2014 summer — Visiting Scientist, Centers for Disease Control and Prevention, Atlanta Georgia, Air Pollution and Respiratory Health Branch, Division of Environmental Hazards and Health Effects, National Center for Environmental Health

2010-present — Senior Environmental Analyst, Bureau of Pollution Control and Prevention, City of Houston. Review private landowner groundwater contaminant plume transport potential and human health risk for Municipal Setting Designation City ordinance. Conduct human health assessment of ambient air pollution data in the Houston Region.

2006-2010 — Senior Environmental Analyst, Mayor's Office City of Houston Office of Environmental Programming. Focused on statistical evaluation and human health assessment of ambient air toxics in the Houston Region. Major contributor to: City ordinance to control ambient air toxics concentrations; assessed and commented on EPA policy impacting the city (e.g., proposed rule on National Emission Standards for Hazardous Air Pollutants from Petroleum Refineries, air toxic regulation for refineries data collection analysis as impacting Houston, residual risk assessment).

2002 -2005 — Air Pollution Researcher, University of Houston, Civil and Environmental Engineering Department, Researcher. Director of air sampling program to support dioxin congener Total Maximum Daily Load (TMDL) project in Houston Region. Sampled ambient and wet and dry deposition flux, evaluated partitioning and developed multiple regression relationships between congeners and meteorological parameters.

2000	Risk Assessment Reviewer, Texas Railroad Commission, Risk Assessment reviewer and co-author of risk assessment guidance for pipeline/oilfield waste including development of default screening levels, dilution attenuation factors, and method for TPH surrogate.
1996 – 1999 (May)	Risk Assessment Regulatory Reviewer, Applied Earth Sciences Consulting, Texas Natural Resource Conservation Commission-LPST Division Risk Assessment Reviewer through a state privatization contract, reviewed more than 200 risk assessments of leaking underground storage tanks including groundwater, soil and air transport.
1999 - 2005	Instructor and Course Author, Applied Environmental Statistics Course (offered through Darcy Environmental),taught all aspects of environmental statistics for risk assessment (including parametric and nonparametric hypothesis testing, trend analysis, normality testing) to professionals in a two day continuing education course at various locations across southern United States several times a year (CEU for Texas Natural Resource Conservation Commission).
1995 - 2000	Risk Assessment Instructor, ASTM Risk-Based Corrective Action Trainer, taught all aspects of risk assessment including toxicology, data assessment, fate and transport to professionals in a three day continuing education course at various locations across the United States.
1989 - 1995	Risk Assessor Statistician and Modeler, (OHM Corporation in Austin, Tx, Jacobs Engineering in St. Louis, Mo and Houston, Tx, Woodward-Clyde Houston, Tx and Applied Earth Sciences, Houston, Tx), risk assessor, environmental modeler and statistician employing groundwater transport (e.g., Modflow, Bioplume/MOC, Domenico), soil vapor transport (Farmer's, Thibideaux-Hwang, Sesoil) and air transport (Box, Gaussian, ISCLT).

Awards and Honors

Eleanor and Mills Bennett Fellowship in Environmental Science, Rice University fellowship awarded to outstanding graduate students, 1996-1997, 1997-1998.

Blackburn Scholarship awarded to fund Environmental Research in Human Health Air Pollution Exposure and Risk Assessment, 1997.

Blackburn Award, Sixth Annual Rice Environmental Conference, for "An Improved Procedure to Estimate Human Exposure-Based Alternative Primary Ambient Ozone Standards," 1998.

National trainer for the ASTM Risk Based Corrective Action Standard, 1996-date.

Designed, Sponsored and Implemented Community Air Pollution Reduction/Awareness Programs:

- Mayor's Keep Houston Beautiful Award, No Mow No More Esplanade Naturalization Program, 2007.
- Governor's Award, Texas Environmental Excellence Award, Condit Elementary School, Condit Kids for Clean Air, 2002
- Mayor's Keep Houston Beautiful Award, Condit Elementary School, Condit Kids for Clean Air, 2002
- National Pollution Prevention Round Table, Most Valuable Pollution Prevention Program, 2002, Condit Elementary School, Condit Kids for Clean Air, 2002
- BP Environmental Excellence Award, Condit Elementary School, Condit Kids for Clean Air, 2002

Major Research Interests

Environmental statistics, human health risk assessment, air, soil and ground water pollution fate and transport.

Submitted Publications

Hoyt, Daniel and Loren H Raun, "Measured and Emission Factor Estimated Benzene and VOC Emissions at a Major US Refinery/Chemical Plant: Comparison and Prioritization," Atmospheric Environment, submitted March, 2015.

Publications

Raun Loren H, Kathy Ensor, Laura A. Campos, and David Persse. "Factors affecting ambulance utilization for asthma attack treatment: understanding where to target interventions," Public Health, March 2015.

Raun Loren H, Katherine B. Ensor, and David Persse. "Using community level strategies to reduce asthma attacks triggered by outdoor air pollution: A case crossover analysis," Environmental Health, August, 2014.

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Ensor, Kathy, Loren Raun, and David Persse. "A case-crossover analysis of out-of-hospital cardiac arrest and air pollution." Circulation. Volume 127, pages 1192-1199, Feb 2013.

Raun, Loren H, Karl Pepple, Daniel Hoyt, Don Richner, Arturo Blanco and Jiao Li. "Community scale air pollution area source impact and public health: Neighborhoods identify an under-regulated area source of metal particulates," Environmental Impact Assessment Review. Volume 41, pages 70-77, January, 2013.

Raun, Loren H., Elena M. Marks, and Katherine B. Ensor, "Detecting improvement in ambient air toxics: An application to ambient benzene measurement in Houston, Texas," Atmospheric Environment, Volume 43 (29), pages 3259-3266. June, 2009.

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Raun, Loren H., Oscar Correa, Hanadi Rifai, Monica Suarez, and Larry Koenig, "Statistical investigation of polychlorinated dibenzo-p-dioxins and dibenzofurans in the ambient air of Houston, Texas," Chemosphere, Volume 60, pages 973-989, 2005.

Correa, Oscar, Hanadi Rifai, Loren Raun, Monica Suarez and Larry Koenig, "Concentrations and Vapor-Particle Partitioning of Polychlorinated Dibenzo-p-dioxins and Dibenzofurans in Ambient Air of Houston, Texas," Atmospheric Environment, Volume 38, Issue 39, pages 6687-6699. December, 2004.

Hopkins, Loren P. A Statistical Investigation of Ozone Exposure Assessment by Direct and Indirect Measurement, Doctoral thesis, Department of Environmental Science and Engineering, Rice University, May, 1998.

Hopkins, Loren P., Katherine Ensor, Matthew P. Fraser, and Hanadi S. Rifai, "Evaluation of the Use of Empirical Ambient Ozone Pollutant Modeling and Subject Activity Logs as an Indirect Measurement of Exposure," Proceedings of the Air and Waste Management Association 91st Annual Meeting, San Diego, California, June, 1998. A&WMA, Paper # 98-MA12.01

Hopkins, Loren P., Katherine B. Ensor and Hanadi S. Rifai, "Empirical Evaluation of Ambient Ozone Interpolation Procedures to Support Exposure Models", Journal of the Air and Waste Management Association, V49, pp. 839-846. 1999

Hopkins, Loren P., Hanadi S. Rifai and Paul LaWare, "Using Compounding Risk as a Guide for Establishing Area-Specific RBCA Risk Limits," Proceedings of the NGWA Petroleum Hydrocarbons and Organic Chemicals in Groundwater: Prevention, Detection and Restoration, November, 1996.

Hopkins, Loren P. and David Bratberg, "Nationwide Survey of Risk Assessment and Risk-Based Corrective Action Procedures," Proceedings of the NGWA Petroleum Hydrocarbons and Organic Chemicals in Groundwater: Prevention, Detection and Restoration, November, 1995.

Bratberg, David and Loren P. Hopkins, "A Comparison of Risk Assessment and Risk-Based Corrective Action Procedures in the United States," Proceedings of the Hazardous Materials Control Resources Institute Superfund XV Conference, Washington, D.C., November 6-8, 1995.

Rifai, Hanadi and Loren P. Hopkins, "The Natural Attenuation Toolbox: A Decision Support System for Evaluating the Appropriateness of Natural Remediation as A Remedial Alternative," Proceedings of the Third Annual Symposium on Bioreclamation, San Diego, Ca., April 1995.

Raparthi, Viru and Loren P. Hopkins, "A Risk Based Evaluation of the Appropriateness of Natural Remediation as a Remedial Alternative in the Vadose Zone," Proceedings of the NGWA Outdoor Action Conference and Exposition on Aquifer Remediation, Ground Water Monitoring, Geophysical Methods, and Soil Treatment, May 2-4, 1995.

Hopkins, Loren P. and Viru Raparthi, "EPA and State Policies on Adjustment of Toxicity Factors for Dermal Absorption," for the Texas Natural Resource Conservation Commission, July, 1994.

Hopkins, Loren P. and Michael F. Marcon, "The Use of Kriging to Optimize Sampling for Risk Assessment and Remediation," Proceedings of the SPE/EPA Environmental Conference 1995.

Durham, Lisa A., Jeff Carman, and Loren P. Hopkins, "Delineation of Hydrostratigraphic Units in a Carbonate Aquifer," Proceedings of the Geological Society of America Meeting, October, 1992.

Hopkins, Loren P. and Scott Edelen, "Optimization of Statistical Hypothesis Testing for Environmental Data Using Nonparametric vs. Parametric Methods," Proceedings of the NGWA Petroleum Hydrocarbons and Organic Chemicals in Groundwater: Prevention, Detection and Restoration, Proceedings, November, 1991.

LaGoy, Peter K., and Loren P. Hopkins, "Practical Considerations in Developing Site Specific Cleanup Levels," Remediation. January, 1991.

Newell, Charles J., Loren P. Hopkins, and Philip B. Bedient. "The HGDB: A New Hydrogeologic Database and Groundwater Modeling Tool," Journal of Ground Water, September-October 1990.

Hopkins, Loren P., Charles J. Newell and Philip B. Bedient, "A Hydrogeologic Database for the EPACML Regulatory Model," Proceedings of the NWWA Petroleum Hydrocarbons and Organic Chemicals in Groundwater: Prevention, Detection and Restoration, November, 1989.

Hopkins, Loren P., A Hydrogeologic Database for Stochastic Groundwater Modeling with Hydrogeologic Specific Applications. Master's thesis, Rice University, Department of Environmental Science and Engineering, May, 1989.

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Newell, C. J., J. F. Haasbeek, L. P. Hopkins, S. E. Alder-Schaller, H. S. Rifai, P.B. Bedient, G. A. Gorry, OASIS: Parameter Estimation System for Aquifer Restoration Models. User's Manual Version 2.0, EPA/600/S8-90/039, 1990.

Other Recent Scholarly Works

L. Raun (2013) Fate and Transport Modeling, in *Encyclopedia of Environmetrics*, A.-H. El-Shaarawi and W. Piegorsch (eds), John Wiley & Sons Ltd: Chichester, UK. DOI: 10.1002/9780470057339.vnn073. Published online 1/15/2013.

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Raun, L. and Hoyt, D., "Measurement and Analysis of Benzene and VOC Emissions in the Houston Ship Channel Area and Selected Surrounding Major Stationary Sources Using DIAL (Differential Absorption Light Detection and Ranging) Technology to Support Ambient HAP Concentrations Reductions in the Community (DIAL Project)," City of Houston Bureau Pollution Control and Prevention, Final Report, June, 2011.

Raun, L., "Severity and Trend Analysis of Benzene and 1,3 Butadiene Concentrations in the ambient Air in the Houston Region: 2000 to 2009," City of Houston Bureau of Air Quality Control.

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Comments of the City of Houston: TCEQ 1,3 butadiene proposed ESL changes. http://www.greenhoustontx.gov/reports/butadiene20080711.pdf

City of Houston Benzene Action Plan, An Interim Report—May 27, 2008 http://www.greenhoustontx.gov/reports/benzeneactionplan-2008may.pdf

Comments of the City of Houston: "National Emission Standards for Hazardous Air Pollutants from Petroleum Refineries," EPA proposed rule, December 20, 2007.

"Houston Regional Benzene Air Pollution Reduction: A Voluntary Plan for Major Sources," City of Houston Mayor's Office of Environmental Programming, Department of Health and Human Services, Bureau of Air Quality Control, major author. 2006. Using results from the TRI, in conjunction with EPA's RSIE and NATA models, the major potential air toxic emitters posing the highest risk to Houstonians were identified. The ambient air toxic data from monitors up and downwind of these facilities were assessed. Statistically significant differences between air contaminant distributions were noted and established as baseline conditions. Facility and process specific emission reduction mechanism recommendations were made. Facilities entering the voluntary agreement would implement emission reduction mechanisms beyond those currently required by regulation. Subsequent reductions in air concentrations from the baseline condition would be tracked. http://www.greenhoustontx.gov/reports/benzenereductionplan.pdf

City of Houston Code of Ordinances, Draft Nuisance Ordinance; Drafted amendment to the nuisance ordinance to specifically address ambient air concentrations of certain hazardous air pollutants.

Current or Recent Board/Committee Participation

Houston Wilderness Board, 2014 to present.
EPA Science Advisory Board, Risk and Technology Review Methods Panel, 2009
Houston Region Air Quality Task Force, 2007
Houston Exposure to Air Toxics Study Advisory Committee, 2007 to 2009

Recent Multiple Reviews or Significant Edits

State of Health, Houston/Harris County, Texas, 2008, 2009, 2010, 2011. Houston Department of Health and Human Services.

Counting on Quality of Life: An Environment Indicator Report, December 2007, Center for Houston's Future.

Comparative Assessment of Air Pollution-Related Health Risks in Houston, Ken Sexton, Stephen H. Linder, Dritano Marko, Heidi Bethel and Philip J. Lupo, doi: 10.1289/ehp.10043, July 5, 2007, online.

The Control of Air Toxics: Toxicology Motivation and Houston Implications, A. Clements, V. Flatt, M. Fraser, W. Hamilton, P. Ledvina, S. Mathur, A. Tamhane, and J. Ward, Rice University, 2007

A Closer Look at Air Pollution in Houston: Identifying Priority Health Risks, Report of the Mayor's Task Force on the Health Effects of Air Pollution, convened by the Institute for Health Policy, The University of Texas School of Public Health under the auspices of The University of Texas Health Science Center at Houston and the City of Houston, Institute for Health Policy Report ES-001-006.

Recent Presentations

Raun, L., Richner, D. "Study of the Accuracy of Emission Factors and Emission Estimating Methods Using the DIAL System. What does DIAL tell us about benzene and VOC emissions from refineries?" EPA webinar presented. October 2012.

Raun, Loren, "What is actually emitted from Area Sources: Results of a Special Study of Metals Recyclers," EPA National Air Quality Conference - Ambient Monitoring 2012, Assessment and Special Studies, Denver, CO, May, 16,2012

Raun, Loren, "Differential Absorption Light Detection and Ranging Measured Emissions at a Houston Ship Channel Area Petroleum Refinery and Chemical Plant: Methods, Results, Comparison to Emission Factors," Southeast Texas Photochemical Modeling Technical Committee, Texas Commission of Environmental Quality, October 19, 2011.

Raun, L., K. Ensor and D. Persse, "Out of hospital cardiac arrest based on the levels of ozone and fine particulates: tracking and predicting at a temporal scale of one hour and a

continuous spatial scale, " Center for Disease Control, Tracking in Action, 2011 National Conference, Atlanta, Georgia, September 14, 2011.

Raun, L., K. Ensor and D. Persse, "Out of hospital cardiac arrest based on the levels of ozone and fine particulates: tracking and predicting at a temporal scale of one hour and a continuous spatial scale, " University of Texas School of Public Health, Houston, Biostatistics Department, Texas September 20, 2011.

Raun, L., Rice Environmental Conference, Houston Air Policy: Compliance, Impact, Limitations, October, 2008.

Raun, L., Rice Air Exchange Meeting, the State of Houston Air and the Voluntary Plan, November, 2007.

Raun, L., Rice Environmental Conference, Houston's Proposed Regional Benzene Air Pollution Reduction: A Voluntary Plan for Major Sources, October 16, 2007.

Raun, L., and A. Blanco, Statistical Techniques to Gain More Information from the Same Set of Air Monitoring Data: A Better Understanding of the Air Pollution Human Health Risk in Houston, U. S. EPA Region 6 16th Annual Quality Assurance Conference, October 20-24, Dallas, Texas 2006.

Raun, L., O. Correa, H.S. Rifai, M. P. Suarez and L. Koenig, Dioxin in Air, U. S. EPA Region 6 13th Annual Quality Assurance Conference, October 20-24, Dallas, Texas 2003.

Pepple, Karl, Brian Yeoman, Loren Raun, Daewon Byun, "Evaluation of Campus Commitments to Sustainability Indicators in DOE Humid Zones," poster presented November 2008.

Raun, L., and Jonathan Ward, "Clearing the Air in Houston: Using Science to Address Policy," Public Health, Washington D.C. November, 2007.

Raun, L., "Houston's Proposed Regional Benzene Air Pollution Reduction: A Voluntary Plan for Major Sources," presented multiple times, City of Houston Environmental Committee, City of Houston Public Hearing, February 12, 2007, Council of Local Mayors, March, 14 2007; Houston Bar Association, Environmental Law Section, Greater Houston Partnership, Informational Public Meeting, Rice University, February 22, 2007.

Raun, L., "Methodology for Tracking the Health of an Airshed: Ambient Benzene and 1,3 Butadiene in Houston Air 1997 to 2007," presented multiple times, City of Houston Bureau of Air Quality Control, Mayor's Office of Environmental Programming.

Raun, L., "Houston Air Monitor Location Sampling Optimization: Benzene, 1, 3 Butadiene and Ozone," 2007 City of Houston Bureau of Air Quality Control

Raun, L., Dan Hoyt and Arturo Blanco, "A Quantitative decision-based voluntary benzene reduction plan for ambient air in the Houston region," EPA Conference, Las Vegas, October 2006.

Raun, L. "Houston Human Health Risk from Air Pathway: Contribution form Shell Oil," City of Houston Bureau of Air Quality Control, April 24, 2006.

Rifai, H.S., and L. Hopkins, The Natural Attenuation Toolbox: A Decision Support System for Evaluating Natural Attenuation, NGWA/AP Conference on Petroleum Hydrocarbons and Organic Chemicals in Ground Water: Detection, Prevention and Restoration, Houston, TX. November 29-December 1, 1995 (Poster Presentation).

Rifai, H. S. and L. Hopkins, An Exposure/Rick Based Screening Approach for Selecting the Natural Attenuation Alternative at Sites, In Situ and On-Site Bioreclamation, The Third International Symposium, San Diego, CA, Apr 24-27, 1995 (Poster Presentation).

Memberships

Air and Waste Management Association
American Association for the Advancement of Science
American Heart Association
Houston Wilderness, Member of the Board
International Society of Environmental Epidemiology
Society of Public Health Educators

Current Funding

Houston Endowment- "Phase II- The impact of air pollution on the incidence of asthma attacks in Houston"
NIH- "Sustainable Solutions to Metal Air Pollution in Disadvantaged Neighborhoods"