Assessment of Spatial Analysis and Decision Assistance (SADA)

Potential for Clean Up

BY

APOSTOLIS SAMBANIS
B.S. University of Illinois at Chicago, 2007

THESIS

Submitted as partial fulfillment of the requirements for the degree of Master of Science in Public Health Sciences (Environmental and Occupational Health Sciences) in the Graduate College of the University of Illinois at Chicago, 2012

Chicago, Illinois

Committee members:
Dr. Michael Cailas
Dr. Christos Takoudis
Dr. John Canar

ACKNOWLEDGMENTS

I would like to begin by thanking God and my family for providing me the strength, love, and patience to complete this thesis. I have been helped by many people and offices that I am not sure where to begin. I would like to begin with my deepest thanks to my advisor, Dr. Michael Cailas. He has been a great asset and without him I would not have the tools I needed to get me to this point. I would also like to thank the other members of my dissertation committee: Drs. John Canar and Christos Takoudis.

In addition, my employer has provided me with the data and technical knowledge I required to complete this assessment. The colleagues I would like to mention in particular: Doug Dorgan, Peter Cambouris, Carl Dawes, Jeff Fitzgibbons, Robert Shebuski, and Steve Stanford. My undergraduate education has helped to provide me with the discipline and research experience I needed to complete this thesis. So, I would like to begin to thank: Natalie Moore, Drs. Fabien Kenig and Caroline Jaraula.

I am truly blessed and this has been an enlightened experience. I have been bettered by completing this work and hope this contribution of scientific literature may better the world we live in.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

TABLE **PAGE**

LIST OF FIGURES

FIGURE **PAGE**

LIST OF ABBREVIATIONS

ATSDR	Agency for Toxic Substances and Disease Registry
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
COCs	Contaminants of Concern
CSM	Conceptual Site Model
hr	Hour
IEPA	Illinois Environmental Protection Agency
kg	Kilogram
LISA	Local Index of Spatial Association
mg	Milligrams
NPL	National Priority List
ppm	Parts per Million
PEL	Permissible Exposure Limit
OSHA	Occupational Safety and Health Administration
RCRA	Resource Conservation and Recovery Act
RfC	Reference Concentration
RfD	Reference Dose
SADA	Spatial Analysis and Decision Assistance
SSLs	Soil Screening Levels

LIST OF ABBREVIATIONS (continued)

SROs	Soil Remediation Objectives
SRP	Site Remediation Program
TACO	Tiered Approach for Corrective Options
TSCA	Toxic Substance Control Act
UCL	Upper Confidence Limit
USEPA	United State Environmental Protection Agency

SUMMARY

Current federal and state regulations related to brownfields promote applicable practices that contain inherent problems. The primary issue with federal and state regulations governing brownfields is that risk assessment measures and spatial distribution of contaminants are not prominently factored in brownfield redevelopment. These boundaries of the contaminants are critical for establishing proper protection of the potential exposed population such as clean-up workers. Recent public domain software developments such as the Spatial Analysis and Decision Assistance (SADA) software can provide a reliable and cost effective tool for developing a comprehensive approach to brownfield redevelopment which will account for the spatial distribution of the contaminants and provide a rational solution to critical operational issues such as hotspots, restrictive zones for the protection of workers, and prioritization of clean-up operations.

Actual data from a real brownfield site in Cook County, Illinois was used in this study to evaluate SADA applicability to brownfield redevelopment. Using SADA, a sample design was established using historical data and implemented at the site. The data captured from the SADA identified site investigation was useful to identify hotspots of contaminants of concern and creation of worker restrictive zones based on future redevelopment. The results for the brownfield site classified statically significant to actual results observed and appears SADA is appropriate tool for brownfield redevelopment.

I. INTRODUCTION AND PROBLEM STATEMENT

The Small Business Liability Relief and Brownfields Revitalization Act, passed in 2001 (Public Law 107-118, H.R. 2869), defines brownfields as "real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant." The extent of contamination encountered at brownfield sites may range from mere surface debris to soil and groundwater contamination that can be hazardous to human and ecological health (Knowlton and Minier, 2001). It is approximated that there are greater than 450,000 brownfields in the U.S and approximately one-half are thought to be contaminated by leaking underground storage tanks (USEPA, 2011).

Brownfield properties historically were not revitalized due in part to distress of environmental contamination which is typically associated with high cleanup costs, extensive cleanup processes, liability risks, and lack of government participation (Schenck, 2004). Brownfield sites have the potential to impair human health and the environment, diminish employment openings and tax revenue, deter economic growth and attract illegal activity; thus, lowering surrounding property values and contributing to the overall decline of the quality of life in the neighborhood (Simon, 2001). Communities across the United States have begun to appreciate brownfield redevelopment can alter a brownfield into productive uses which can subsequently bring improved public health and environment, economic growth and increases in employment openings (Ruiz-Esquide, 2004).

A. **<u>Brownfields in Illinois</u>**

Brownfields in Illinois may be challenging for redevelopment and are often located in economically desirable areas (CMAP, 2008). Brownfield properties differ in age, location, past use, and size (USEPA, 2006). According to the USEPA, there are currently approximately 773 brownfields in Illinois as displayed on Figure 1 (USEPA, 2011).

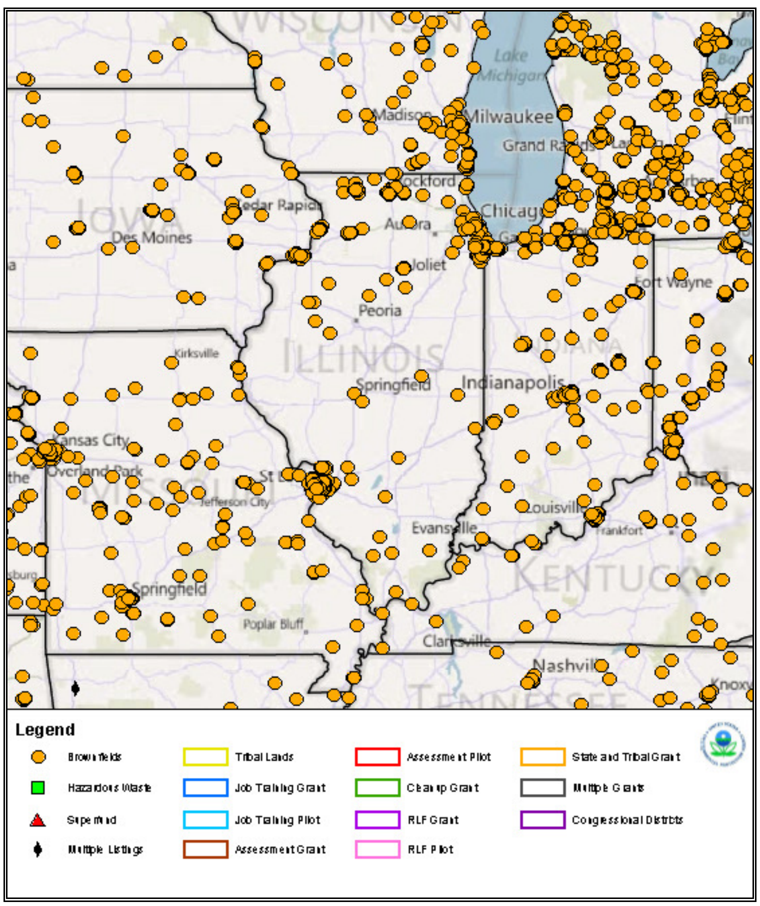


Figure 1. Brownfield sites in Illinois.

According to the Illinois Environmental Protection Agency (IEPA) voluntary clean-up program known as the Site Remediation Program (SRP), between July 1996 and December 2007 approximately 3,029 sites were registered (CMAP, 2008). Even if the site has completed it's clean up of the contamination to satisfaction of IEPA laws and regulations by receiving a No Further Remediation letter; these sites still have perceived contamination and subsequently are considered brownfield sites. In addition, approximately 17,000 acres of land in Illinois has been remediated and registered with the SRP (CMAP, 2008). Most SRP sites are located within Cook County, with approximately half of the sites in the City of Chicago (CMAP, 2008). Based on the RCRAInfo database, there are approximately 38,051 prospective brownfields in the northeastern Illinois region and the locations of these sites are in areas with potential economic growth (e.g. along transportation corridors; see CMAP, 2008).

B. Regulatory Framework for Brownfields

1. Federal laws governing Brownfields

The two most significant federal laws that regulate brownfields are the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Resource Conservation and Recovery Act (RCRA) (CERCLA, 1980 and Powell, 1998). CERCLA and RCRA determine parties who are potentially liable for cleanup costs at contaminated sites: owners and operators of the property, generators of the hazardous substances, and transporters of the hazardous substances (Murphy, 1986). Under CERCLA, anyone could be held accountable for all the costs of cleanup, even if they only contributed a small proportion of the waste at the site (USEPA, 1989). A recent purchaser of a property could be held accountable for all the expenses of cleanup at a site without the proper due diligence (USEPA, 1989). The government soon recognized that CERLCA was deterring brownfield redevelopment. In 1995, the USEPA presented the Brownfields Action Agenda to help simplify the government's role, to make funds accessible for pilot projects to examine redevelopment approaches and to deliver direct assistance to those concerned with redeveloping high risk sites (USEPA, 1995a). These efforts were strengthened in 2001 with the passing of the federal Small Business Liability Relief and Brownfields Revitalization Act (also known as the Brownfields Law) which expanded USEPA's assistance (Public Law 107-118, H.R. 2869).

2. **Illinois laws governing Brownfields**

The State of Illinois law that is most applicable to contaminated sites is the Illinois Environmental Protection Act (Layman and Northrup, 1998). As stated in the Memorandum of Understanding between the IEPA and USEPA on the Illinois Site Remediation Program (SRP), Illinois Tiered Approach to Corrective Action Objectives (TACO), and the Environmental Remediation Programs administered by the Region 5 Waste, Pesticides, and Toxic Division under RCRA and TSCA dated June 1997, IEPA and Region V began developing strategies to promote the remediation and redevelopment of brownfield sites (IEPA, 1997). TACO is the IEPA's process for developing remediation objectives for contaminated soil and groundwater (IEPA, 1997). The IEPA has operated SRP, which provides management, aid, and oversight to owners and operators of sites in Illinois who implement site assessment and remediation; in addition, IEPA has established a consistent cleanup objectives process known as TACO (IEPA, 1997). TACO allows site owners and developers to remediate the site to the proper tier based on risk (IEPA, 1997). Nowadays, brownfield development is being hampered by the decrease in federal and state funding.

C. **Objectives of the study**

Current federal and state regulations related to brownfields promote applicable practices that contain inherent problems. The primary issue with federal and state regulations governing brownfields is that risk assessment measures are not prominently factored in brownfield redevelopment. A case in point is the lack of a comprehensive approach to brownfield redevelopment which will account for the spatial distribution of the contaminants. These boundaries of the contaminants are critical for establishing proper protection of the potential exposed population such as clean-up workers. Recent public domain software developments such as the Spatial Analysis and Decision Assistance (SADA) software can provide a reliable and cost effective tool for developing a comprehensive approach to brownfield redevelopment which will account for the spatial distribution of the contaminants and provide a rational solution to critical operational issues such as hotspots, restrictive zones for the protection of workers, and prioritization of clean-up operations. The spatial defined information would allow site investigators to visualize the extent of the contamination; therefore, minimizing the uncertainty while providing accurate results to reduce expenditures during data collection and remediation.

The spatial database used in this study (SADA) was developed by the University of Tennessee in Knoxville and the USEPA and according to SADA documentation the original objective was, "…purpose of the effort was to develop tools that would integrate human health and ecological risk assessment with geospatial processes in a manner that could directly impact environmental restoration decisions." (SADA, 2008). SADA appears to provide a number of other useful applications such as the establishment of restrictive zones for hazardous work areas and a valuable tool for estimating the contaminated volume for clean-up operations. The overall objective of this study was to assess the applicability of SADA as an analysis, interpretation, and design tool for brownfield redevelopment. The specific objectives of this study are:

- To demonstrate the use of SADA to identify sampling locations by taking into account previous studies as well as potential polluting sources;
- To evaluate the applicability of SADA for the selection of samples based on financial constraints;
- To assess the applicability of SADA for the identification of potential high risk areas in a brownfield site with the objective to protect construction workers and trespassing recreational persons; and,
- The use of SADA to prioritize clean-up operations and creation of restrictive zones.

To this aim actual data from a real brownfield site in Cook County, Illinois was used in this study. This study is the first time the applicability of this health risk spatial database has been investigated for such a scope. The results from this study could be used as a demonstration project to promote the use of risk assessment and spatial visualization techniques as a useful tool for brownfield redevelopment.

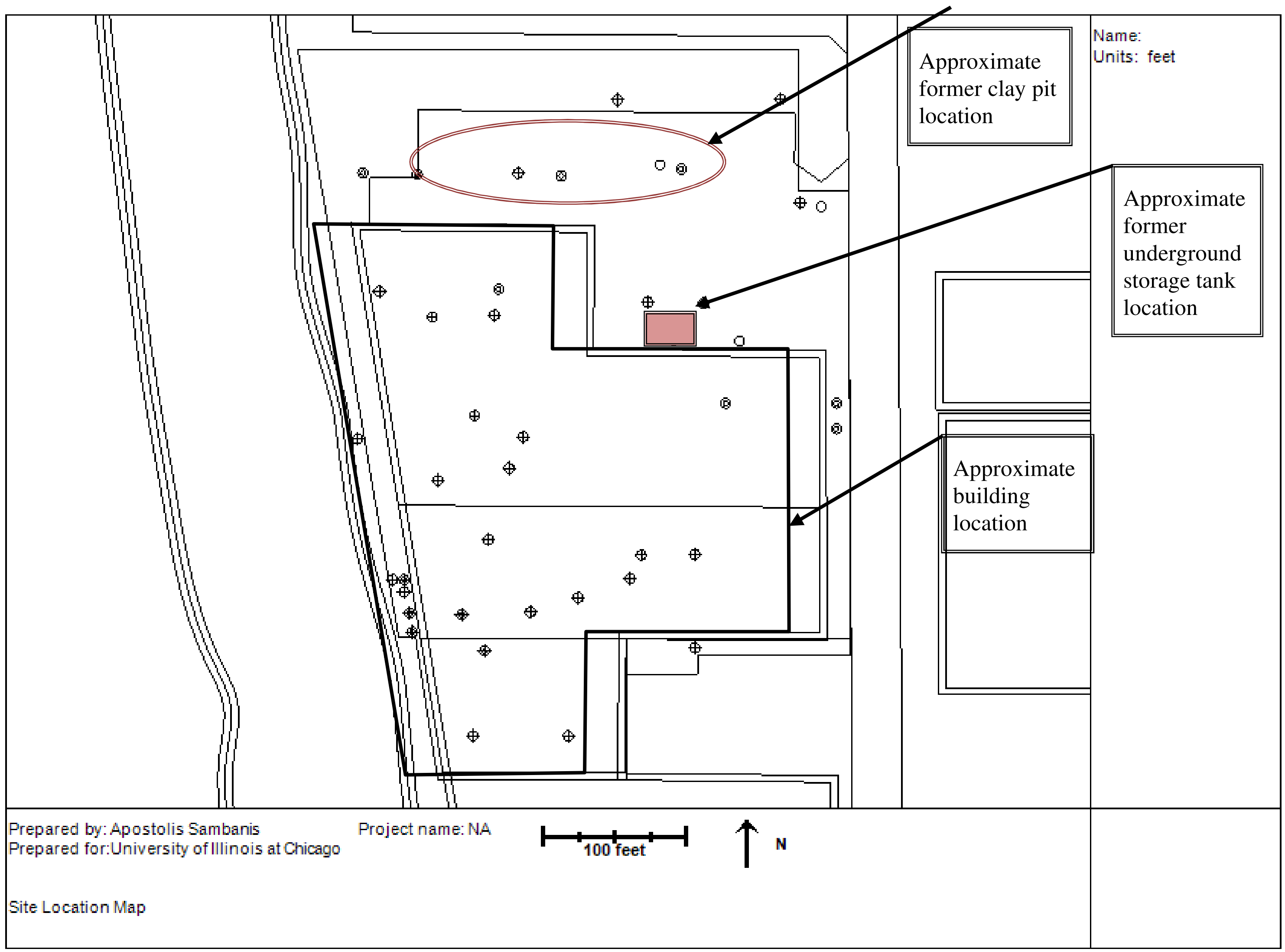


Figure 2. Site location map

II. METHODS AND MATERIAL

A. History of the Property under Investigation

An actual brownfield site, from heron termed as the Property, will be used for this demonstration project. The Property is an approximate 3.68-acre parcel of land that currently consists of one, one-story industrial building (Figure 2). The Property was used for metal stamping and die drawing for approximately 58 years. The surrounding properties are primarily industrial and mixed commercial use. Previous site investigations conducted at the Property identified that unknown fill material were present within the location of a former clay pit; and that an abandoned heating oil underground storage tank was present on the north part of the Property. This Property fits the criteria of a brownfield due to the potential presence of contamination.

The current study used actual soil and groundwater data from this brownfield site to assess the objectives stated earlier. Multiple sites were being investigated within Cook County, Illinois but the Property was ideal for this investigation for the following reasons:

- The site fulfills the criteria of a brownfield.
- The site had historical investigation data that could be used as a base to determine the contaminants of concern.
- The site was under the suspicion to contain contamination.

- The extent of contamination encountered at the site was unclear and a need for a fiscally conservative sample design was identified in order to prioritize the clean-up operations.

It should be noted that landmarks and other identifiable spatial references have been altered or removed in order to protect the confidentially of the Property.

B. **Historical Investigations**

In the past, three on site investigations occurred to identify and delineate contaminants of concern (COCs) at the Property. The first two site investigations comprised the historic data record that was used in this study to identify potential impacts associated with the heating oil underground storage tank and former clay pit located on the northern half of the Property. To clarify:

- 1st study objectives/description: As depicted on Figure 2, three soil probes (open circle symbols) were advanced in the vicinity of the heating oil underground storage tank and two were advanced near the location of the former clay pit
- 2nd study objectives/ description: As depicted on Figure 2, eight soil probes (double circle symbols) were completed of which a total of six soil samples were collected and analyzed to further delineate the contamination identified in the first site investigation.

Based on the data from the first two historical site investigations, the following contaminants were identified:

- Soil contaminated with cis-1,2-dichloroethene trans-1,2-dichloroethene, and trichloroethylene (TCE) was observed at concentrations exceeding the Illinois Environmental Protection Agency (IEPA) Tiered Approach to Corrective Action Objectives (TACO) Tier 1 Soil Remediation Objectives (SROs) within soil samples collected from the northwestern of the building on the Property.
- Concentrations of benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, dibenz(a,h)anthracene, indeno(1,2,3-cd)pyrene, naphthalene and mercury in three soil samples on the northern portion of the Property exceed their IEPA TACO Tier 1 SROs.
- Lead contamination is present on the central portion of the Property near the location of an abandoned heating oil UST. Concentrations of lead in two soil samples collected in the vicinity of the abandoned heating oil UST exceed IEPA TACO Tier 1 SROs.

The historical data indicate high levels of contaminants within the targeted areas (e.g., clay pit or heating oil underground storage tank). Due to financial limitations, which are common with such actual filed projects, the list of selected contaminants is not exhaustive, nonetheless the selected COC are likely to me the most detrimental to human health (i.e., trichloroethylene, mercury, and lead) and the measures taken to remedy their presence will remedy the presence of all the others as well.

C. **Selected Contaminants of Concern**

1. **Trichloroethylene**

Trichloroethylene (TCE), also known as trichloroethlene, is a solvent used mainly in metal degreasing and cleaning processes (ATSDR, 1997). TCE can be absorbed through the lungs, mucous membranes, gastrointestinal tract, and the skin (ATSDR, 1997). TCE is primarily metabolized in humans to trichloroacetic acid and trichloroethanol, with most of the absorbed dose expelled in urine (ATSDR, 1997).

Human and animal data postulate that exposure to TCE can cause toxic effects on the liver, kidney, blood, skin, immune system, reproductive system, nervous system, and cardiovascular system (ATSDR, 1997). Acute inhalation exposure to TCE affects the central nervous system with symptoms such as headache, dizziness, nausea, and unconsciousness (ATSDR, 1997). The cardiovascular effects associated with TCE exposure comprise of tachycardia, extrasystoles, electrocardiography abnormalities, and precordial pain (ATSDR, 1997). Reference Doses (RfDs) and Reference Concentrations (RfCs) for subchronic and chronic oral and inhalation exposure to TCE remain under review by the USEPA (USEPA, 1992). Chronic inhalation exposure to TCE prompted lung and liver tumors in mice and testicular Leydig cell tumors in rats (ATSDR, 1997).

2. **Lead**

Lead is a natural element that is continuously found in water and soil. Soil content differs with the location it is found; typically, 3000 micrograms per gram in urban areas, and 20,000 micrograms per gram near point sources (ATSDR, 1993). Human exposure to lead occurs primarily through diet, air, drinking water, and ingestion of dirt and paint chips (ATSDR, 1993).

Inorganic lead is not proficiently absorbed through the skin; therefore, this route does not contribute to the total body lead burden (ATSDR, 1993). Lead absorbed into the body is circulated to three major compartments: blood, soft tissue, and bone (ATSDR, 1993). Exposure to lead is documented by elevated blood lead levels (ATSDR, 1993).

According to ATSDR (1993), lead is a multi-targeted toxicant, producing effects in the gastrointestinal tract, hematopoietic system, cardiovascular system, central and peripheral nervous systems, kidneys, immune system, and reproductive system. In addition, other organs or systems affected by exposure to lead are the kidneys, immune system, reproductive system, gastrointestinal tract, and liver (ATSDR, 1993). These effects emerge at elevated blood lead levels (ATSDR, 1993).

The USEPA has not established an RfD for lead because it is a non-threshold toxicant (ATSDR, 1993). The USEPA has established a screening level of 400 ppm for lead in soil (USEPA, 2001a). Inorganic lead and lead compounds have been evaluated for carcinogenicity by the USEPA (USEPA, 2001a).

3. **Mercury**

Mercury is a natural element present in multiple forms and in several oxidation states and used in a wide assortment of products (ATSDR, 1989). Exposure to mercury may occur in both occupational and environmental settings (ATSDR, 1989). The form and oxidation state determines the amount of mercury absorbed, distributed, metabolized, and excreted by humans and animals (ATSDR, 1989). The elimination half-life is 35 to 90 days for elemental mercury and mercury vapor and approximately 40 days for inorganic salts (ATSDR, 1989).

Toxicity resulting from subchronic and chronic exposure to mercury and mercury compounds usually involves the kidneys and/or nervous system, the specific target and effect being dependent on the form of mercury (ATSDR, 1989). A subchronic and chronic inhalation RfC of 0.0003 mg of mercury per cubic meter for inorganic mercury (ATSDR, 1989) is established on neurological disorders following long-term occupational exposure to mercury vapor (ATSDR, 1989). USEPA has established that inorganic mercury is not classifiable as a human carcinogen and mercuric chloride and methyl mercury is classifiable as a possible human carcinogen based on studies conducted on rats (ATSDR, 1989). The following table (Table I) helps to summarize the applicable regulation and guidelines applicable to the COCs identified (limited information based on provided references).

TABLE I

SUMMATION OF REGULATIONS AND ADVISORIES OF THE CONTAMINANTS OF CONCERN

Analyte	Description	Information	References
Trichloroethylene	Reference Dose	Under Review	ATSDR, 1997
	Carcinogenic Classification	Under Review	ATSDR, 1997
	Construction Worker Inhalation	12 ppm	IEPA, 1997
Lead	Reference Dose	Not Applicable	ATSDR, 1993
	Carcinogenic Classification	Group B2 (probable human carcinogen)	ATSDR, 1993
	United States Environmental Protection Agency Toxic Substance Control Act Section 403 Bare Soil in Children's Play Areas	400 ppm	USEPA, 2001a
Mercury	Reference Concentration	0.0003 mg/m^3	ATSDR, 1989
	Carcinogenic Classification	Group D (not classifable)	ATSDR, 1989
	Construction Worker Inhalation	0.1 ppm	IEPA, 1997

Occupational Safety and Health Administration (OSHA) has established permissible exposure limits (PEL). PEL are legal limits for exposure of an employee to a chemical substance. A PEL is usually given as a time-weighted average (TWA). A TWA is the average exposure over a specified period of time, usually a nominal eight hours. For the COCs in this study:

- Trichloroethylene: Construction Industry is 100 ppm TWA (29 CFR 1926.55);
- Mercury: General Industry is 0.1 mg/m^3 TWA (29 CFR 1910.100)

- Lead: Construction Industry is 0.05 mg/m^3 TWA (29 CFR 1926.62)

It should be noted that OSHA limits generally are not as conservative as those established by the IEPA and USEPA.

These contaminants are present at numerous sites across the United States and have been found to be extremely detrimental to human health. High levels of mercury, lead, and trichloroethylene have been found at 714, 861, and 1,272 USEPA National Priority List (NPL) sites, respectively, out of a total of approximately 1,714 current or former NPL sites. In addition, the 2007 CERCLA Priority List of Hazardous Substances ranks lead, mercury, and trichloroethylene number 2, 3, and 16 out of total of 275 substances listed.

D. Determination of Exposure Criteria

The Property under investigation is currently vacant. On this area there was a facility which was historically used as a manufacturing facility and within the boundaries of this area there was never a residential development. Due to the site currently being vacant, the only two potential exposed populations in the foreseeable future will be construction workers redeveloping the site and recreational (trespassing) people. It should also be noted that groundwater is not a factor because the facility was historically connected to a large metropolitan water distribution system.

The data as displayed in Table II, is from the two historical site investigations conducted. As highlighted in green, several samples exceeded federal and state soil remediation objectives; specifically, the IEPA TACO Tier 1 remediation objectives for the inhalation exposure route for the construction worker scenario for trichloroethylene and mercury; or USEPA TSCA Section 403 remediation objective for bare soil in children's play area for lead (2001a). It should be noted and as discussed previously that these historical site investigations only focused on the northern half of the Property around the former heating oil underground storage tank and clay pit. Suspiciously high levels of the soil concentrations of the COCs with no vertical and horizontal extent of the COCs were determined. As part of the current study a conceptual site model (CSM) was created to determine how these COCs travel into and through the site.

TABLE II

HISTORICAL SITE INVESTIGATION RESULTS

Parameter	Trichloroethylene	Lead	Mercury
Units	mg/kg	mg/kg	mg/kg
2006 Investigation	< 0.0065	400	0.27
	< 0.0054	640	5.3
	< 0.0056	660	0.16
	< 0.0068	530	0.12
	< 0.0045	19	< 0.1
	< 0.0044	26	< 0.1
	12	690	0.21
2000 Investigation	NA	262	NA
	NA	981	NA

NA - Not Analyzed

E. **Conceptual Site Model**

A CSM is an explanation of how contaminants arrive into a system, transported within the system, and potential routes of exposure to humans (USEPA, 1996). It provides a structure for evaluating risks from contaminants, establishing remedial strategies, defining source controls, and how to address unacceptable risks (USEPA, 1996).

When developing a CSM it is essential to determine how the contaminants behave, migrate, and their ultimate fate within a system (USEPA, 1996). CSMs are an instrument to implement many management decisions; the restrictions and necessities related with the management decision determine the appropriate depth and extent of the CSM (USEPA, 1996).

The historical site investigations introduced and addressed various CSM components for the Property, which helped guide the identification data gaps for the most recent investigation (i.e., current study). The historical site investigations were conducted in targeted areas (e.g. former clay pit and UST); however, this was not allowing investigators to establish proper spatial boundaries of the COCs. The CSM used available data from the historical investigations and help to identify data that are not yet available for incorporation into the CSM. The scope for this CSM, and the focus for most of the fate, transport, and exposure evaluations (see Table III) below:

TABLE III

CONCEPTUAL SITE MODEL FOR SITE UNDER INVESTIGATION

Source	Environmental Exposure Media	Exposure Point	Exposure Route	Exposed Population
Industrial Area	Soil	Subsurface construction	Inhalation of Particulates	Construction Workers
Industrial Area	Soil	West side of Property near River	Inhalation of Particulates	Recreational Persons

A need for additional data to investigate this scope was noted and a sample design was created within SADA.

F. Spatial Analysis and Decision Assistance

As described by Spatial Analysis and Decision Assistance (SADA) website, “Spatial Analysis and Decision Assistance (SADA) is free software that incorporates tools from environmental assessment fields into an effective problem solving environment. These tools include integrated modules for visualization, geospatial analysis, statistical analysis, human health risk assessment, ecological risk assessment, cost/benefit analysis, sampling design, and decision analysis. The capabilities of SADA can be used independently or collectively to address site specific concerns when characterizing a contaminated site, assessing risk, determining the location of future samples, and when designing remedial action." SADA is developed in The Institute for Environmental Modeling at the University of Tennessee and by the USEPA.

SADA was used within this study to create an effective sample design to investigate the extent of contamination. Once the historical site investigation data was obtained we used SADA to determine the hot spot locations, access the risk of the contamination identified, and create restrictive zones for future workers at the site.

G. <u>**Sample Design**</u>

The short comings of the historical site investigations to properly determine the spatial distribution of the COCs established a need for proper sample design. The sample design needed to adequately determine spatial distribution but take in account the financial constraints of the project. SADA has multiple sample design strategies that may be chosen. The two major categories as listed in SADA for sample designs are initial and secondary sampling (SADA, 2008). Initial sample designs are used when no prior information about the site is available to regulate a sample design (SADA, 2008).

Secondary sample designs are used when sampled data and/or modeled results already exists in a SADA file to regulate future sampling locations; they are reliant on the historical samples (SADA, 2008). Based on availability of our two historical site investigations a secondary sample design was used. SADA contains the following secondary sample designs:

- Judgmental Design

- Threshold Radial
- Adaptive Fill
- High Value
- Area of Concern Boundary
- Ripley's k
- Moran's I
- Geary's C

Ripley’s k statistic is a measure of neighborhood sampling density and is evaluated at central intersecting point known as a “node” in the grid (Equation 1 see Appendix A). By specifying a simple search neighborhood about that “node” assessing the number of data points found there (Ripley, 1977) and repeating this for each node creates a complete map. The Ripley’s k design locates samples in those areas with the lowest sampling density in the nearby vicinity (Ripley, 1977). Ripley’s k would avoid areas with a higher sampling density and concentrate in a less densely sampled area (Ripley, 1977). Based on our discussion above and the characteristics of samples from the two historical site investigation collected at the Property; Ripley’s k method was chosen.

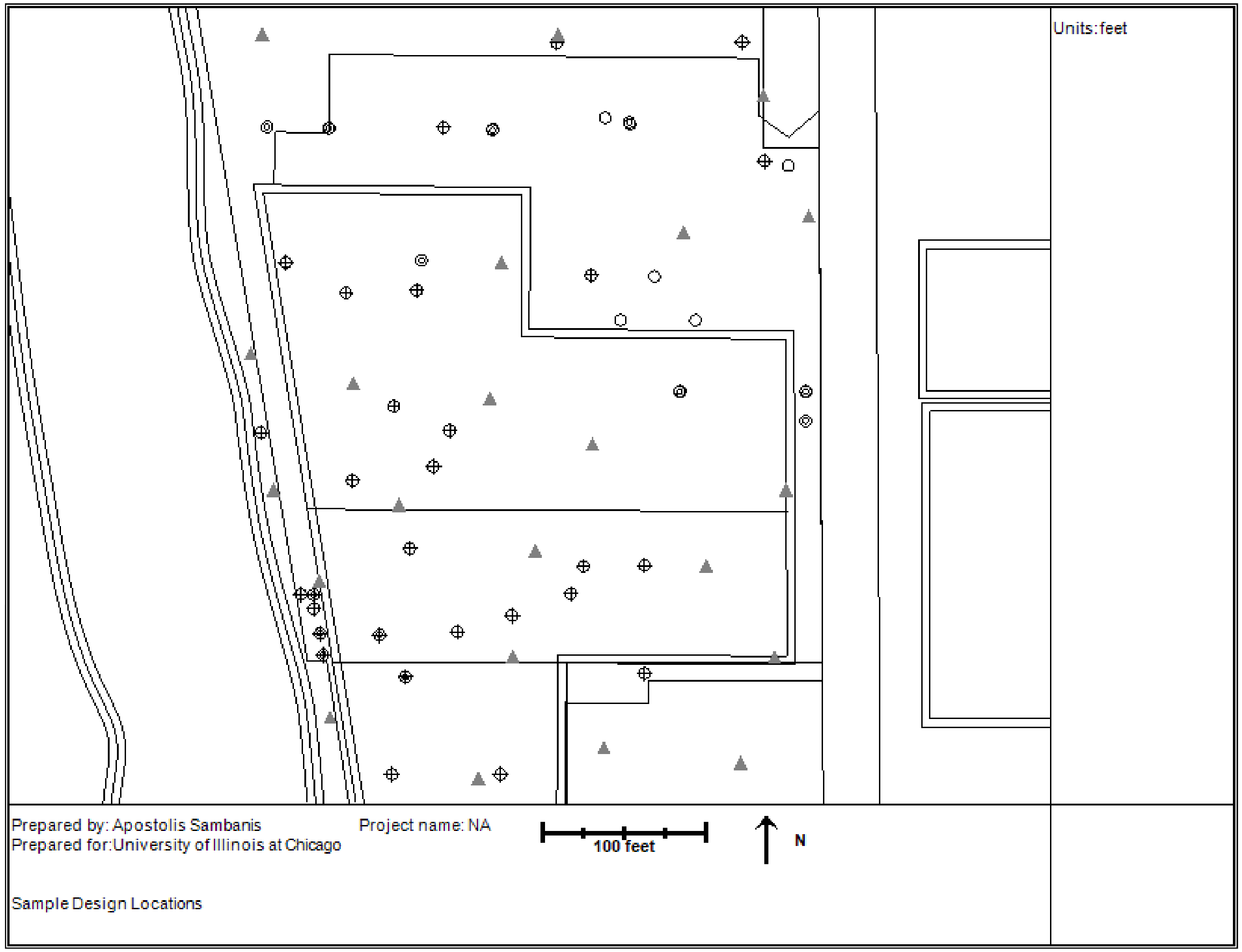


Figure 3. Sample design map (triangle symbols denotes sample design sample points)

Using this method, seven variables from the historical site investigations were used as input variables in to SADA:

- **Variable 1**, "ID," is the soil probe or monitoring well location. The variable is a series of letter and numbers which represent type of sample (SP is soil probe) and the number is the order in which it was sampled.
- **Variable 2 and 3**, "Easting" and "Northing," represent the geographic coordinate (i.e. X, Y) for each "ID,"
- **Variable 4**, media, is the phase in which sample was taken. For example, soil would be type of porous media in which contaminate may travel.
- **Variable 5**, "Contaminant Name," is the type of contaminant identified and sampled.
- **Variable 6**, "Value," is the result of the laboratory analysis for the specific contaminate in the particular sample. If non-detection values were reported by the laboratory for the particular sample a full non-detection value was inputted to be conservative.
- **Value 7**, "Depth," is feet below ground surface in which the sample was obtained.

After inputting the historical data, we developed a sample design using the Ripley's k method described earlier within SADA to delineate the contamination associated with the three most detrimental COCs (Figure 3). The secondary sample design performed by SADA identified the new locations that are required in order to have a better representation of the extent of contamination. Based on this design a new investigation (i.e. the current study) was undertaken at the Property in 2008. The Property is approximately 3.68 acres, therefore during the SADA designed site investigation; approximately one soil probe was advanced per approximately 0.14 acres. As depicted in Figure 3, the locations on the map with a triangle symbol were the SADA identified sampling points. These additional sampling points will be were help to identify areas where the extent of the COCs could be furthered evaluated.

H. **Site Sampling**

Based on financial constraints a total of twenty-six (26) samples points were justifiable. The SADA identified investigation advanced 26 soil probes (cross hatch symbols) across the Property to a depth of sixteen (16) feet below ground surface with two of the soil probes advanced to thirty (30) feet below ground surface and were based on the general vicinity of SADA developed sampled design as depicted on Figure 3.

Based on all three site investigations, a total of 40 soil probes have been advanced at the site and 3 temporary monitoring wells were installed at the site to investigate groundwater. Each soil probe was advanced using a Geoprobe® sampling system and sampled using direct push sampling techniques. Each soil sample was visually classified and logged. Upon collection, a discrete sample from each two foot interval was screened using a photoionization detector.

One soil sample from these soil probes were collected for laboratory analysis using USEPA SW846 Method 5035A from the interval exhibiting the greatest indication of contamination. To characterize the vertical extent of COCs as necessary, at various locations a second sample was collected from deeper intervals appearing free of contamination (at contaminated locations) or native material underlying fill material. Soil samples collected were sent to a National Environmental Laboratory Accreditation Program (NELAP) accredited laboratory for Volatile Organic Compounds (VOCs, USEPA Method 8240/8260 and Resource Conservation and Recovery Act (RCRA, USEPA Method 6010B/7473) Metals analyses.

Groundwater samples were collected at each of the three temporary wells using a one-inch diameter, ten-foot long, polyvinyl chloride (PVC) section of 0.01-inch slotted screen. After installation of the temporary wells, the wells were purged using a peristaltic pump and polyethylene tubing and filtered in an effort to remove silt that may have accumulated. After purging, the peristaltic pump and polyethylene tubing were used to collect groundwater samples. The groundwater samples collected were sent to a National Environmental Laboratory Accreditation Program accredited laboratory for VOCs and RCRA Metals analyses. In addition, pH, specific conductance and temperature were also measured during groundwater sample collection. After the completion of the soil probes and the temporary monitoring wells, the temporary monitoring wells were removed and the probes will be abandoned by backfilling each probe with granular bentonite mixed with the soil cuttings. The data was collected following USEPA Protocol/Standard Methods.

III. RESULTS AND DISCUSSION

A. **Statistical Comparisons**

Most states have adopted the federal regulations and standards into their State-level regulatory codes and are consequently authorized to carry out primary implementation and enforcement responsibilities for the USEPA requirements. TACO is the Illinois EPA's method for establishing remediation objectives for contaminated soil and groundwater. As stated in the Memorandum of Understanding between the IEPA and USEPA dated June 1997; the SRP, TACO, and all other environmental remediation programs are managed by the Region 5 Waste, Pesticides, and Toxic Division under RCRA and TSCA. TACO Tier 1 remediation objectives for residential, construction worker, and industrial/commercial uses were created directly from the technical concepts and principles established by USEPA "Soil Screening Guidance: User's Guide", EPA/540/R-96/018,PB96-963505 (1996)). It should be noted the recreational person scenario has not been developed by the IEPA.

These remediation objectives protect human health and take into account site conditions and land use (USEPA, 1996). Human exposure route(s) can be excluded from further consideration provided the requirements in Subpart C of TACO are met (IEPA, 1997). The human exposure routes in question with most brownfield redevelopment projects are: inhalation, soil ingestion and groundwater ingestion (including migration to groundwater) (USEPA, 1996). When contaminant concentrations do not exceed background concentrations for soil and/or groundwater, evaluation under any of the other tiers may not be required (IEPA, 1997).

TCE and mercury soil concentrations were compared to TACO. However, TACO has no construction inhalation exposure route established for lead. Thus, Lead concentrations were compared to concentrations that exceed the 400 mg/kg; this is well below IEPA established soil remediation objectives for all land use scenarios in TACO (35 IAC Part 724) and parallels the USEPA TSCA Section 403 remediation objective for bare soil in children's play area of 400 mg/kg total lead (USEPA, 2001a).

As stated earlier, in the foreseeable future construction worker and recreational person (trespassing) scenario will be a potential exposure scenario to be taken in to consideration. The data as displayed in Table IV, were compared to IEPA TACO Tier 1 remediation objectives for the inhalation exposure route for the construction worker scenario for trichloroethylene and mercury; or USEPA TSCA Section 403 remediation objective for bare soil in children's play area for lead (USEPA, 2001a). Six of the nine samples collected in the historical site investigation exceeded these remediation objectives; in comparison, eight of the thirty nine samples total exceeded in the SADA identified investigation.

TABLE IV

SADA IDENTIFIED SITE INVESTIGATION RESULTS

Parameter	Trichloroethylene	Lead	Mercury
Units	mg/kg	mg/kg	mg/kg
2008 Investigation	NA	72	0.048
	< 0.0049	NA	NA
	110	10	< 0.028
	< 0.0047	NA	NA
	< 0.0051	19	0.029
	< 0.0051	220	0.13
	< 0.0055	NA	NA
	< 0.0053	1800	0.13
	NA	18	NA
	< 0.0077	360	1.5
	NA	NA	NA
	< 0.0057	260	0.28
	< 0.0047	NA	NA
	< 0.0066	190	12
	< 0.005	NA	NA
	NA	2600	0.85
	NA	11	0.028
	NA	19	0.037
	< 0.0051	NA	NA
	8.7	NA	NA
	690	NA	NA
	25	NA	NA
	< 0.0063	NA	NA
	0.074	NA	NA
	NA	NA	NA
	< 0.005	NA	NA
	< 0.0057	NA	NA
	< 0.0048	NA	NA
	< 0.0051	NA	NA
	< 0.0046	NA	NA
	< 0.0052	NA	NA
	< 0.0044	NA	NA
	< 0.0049	NA	NA
	< 0.0047	NA	NA
	< 0.0062	NA	NA
	< 0.0048	NA	NA
	3.3	NA	NA
	< 0.0049	NA	NA
	< 0.0056	NA	NA

NA - Not Analyzed

It may seem the historical site investigation was better by comparison if you only take in account the percentage detected above the remediation objectives but if you look at the underlying statistics; this indicates samples collected in the SADA identified site investigation were indeed critical. As displayed in Tables V and VI, the maximum concentration and average concentrations of the COCs detected in the soil samples increased from the historical samples when compared to the SADA identified site investigation.

TABLE V

STATISITICS OF THE HISTORICAL SITE INVESTIGATION

Analyte	Trichloroethylene	Lead	Mercury
Count	7	9	7
Min	0.0044	19	0.1
Max	12	981	5.3
Mean	1.72	468	0.89
Percentage of samples above remediation objectives	14.2%	55.5%	71.4%
Standard Deviation	4.53	321	1.94
Variance	20.6	103346	3.78
Median	0.0056	530	0.16

TABLE VI

STATISITICS OF THE SADA IDENTIFIED SITE INVESTIGATION

Analyte	Trichloroethylene	Lead	Mercury
Count	31	12	11
Min	0.0044	10	0.028
Max	690	2600	12
Mean	26.9	465	1.37
Percentage of samples above remediation objectives	9.38%	16.6%	54.5%
Standard Deviation	125	836	3.56
Variance	15549	699500	12.6
Median	0.0056	131	0.13

In Table VII, skewness is a measure of symmetry. Skewness for a normal distribution is zero, and any symmetric data should have a skewness near zero. Positive values for the skewness measure, which is the case in our data, indicates the data that are skewed right or not normally distributed. Kurtosis is a measure of whether the data are peaked or flat relative to a normal distribution. Data sets with high kurtosis, which is the case in our data, tend to have a distinct peak near the mean, decline rather rapidly, and have heavy tails. Thus we are able to rule out the Normal Student's t 95% upper confidence level. These results are comparable to those displayed in our histograms displayed in Tables VIII, IX, and X.

It is essential to visualize the data distribution of the site to help clarify how the data is behaving and identify any problems. This is made possible by creating histograms (created within SADA) for each COC. As displayed in Figure 4, 5 and 6, the data distribution appears to be not normal. The trends indicated positive skewness (tail extending to the right) and positive kurtosis (high peak). It appears that only small frequency of soil samples display high concentration of the COCs.

However, when calculating the 95% upper confidence levels for exposure evaluation the value need to be accurate due to it being essential for our risk equations which is further described in the next section.

TABLE VII

DESCRIPTIVE STATISTICS

Analyte	Trichloroethylene	Lead	Mercury
Minimum Overall	0.0044	10	0.028
Maximum Overall	690	2600	12
Minimum Depth	2	2	2
Maximum Depth	24	12	12
Number of Samples	29	19	17
Median	0.0056	260	0.13
Coefficient of Variance	4.4	1.4	2.4
Interquartile Range	0.0018	640	0.23
Normal-Student's t 95% Upper Confidence Level	70	760	2.5
Lognormal-Land's H 95% Upper Confidence Level	730	4100	6.1
Skewness	5.2	2.2	3.2
Kurtosis	27	4.9	11

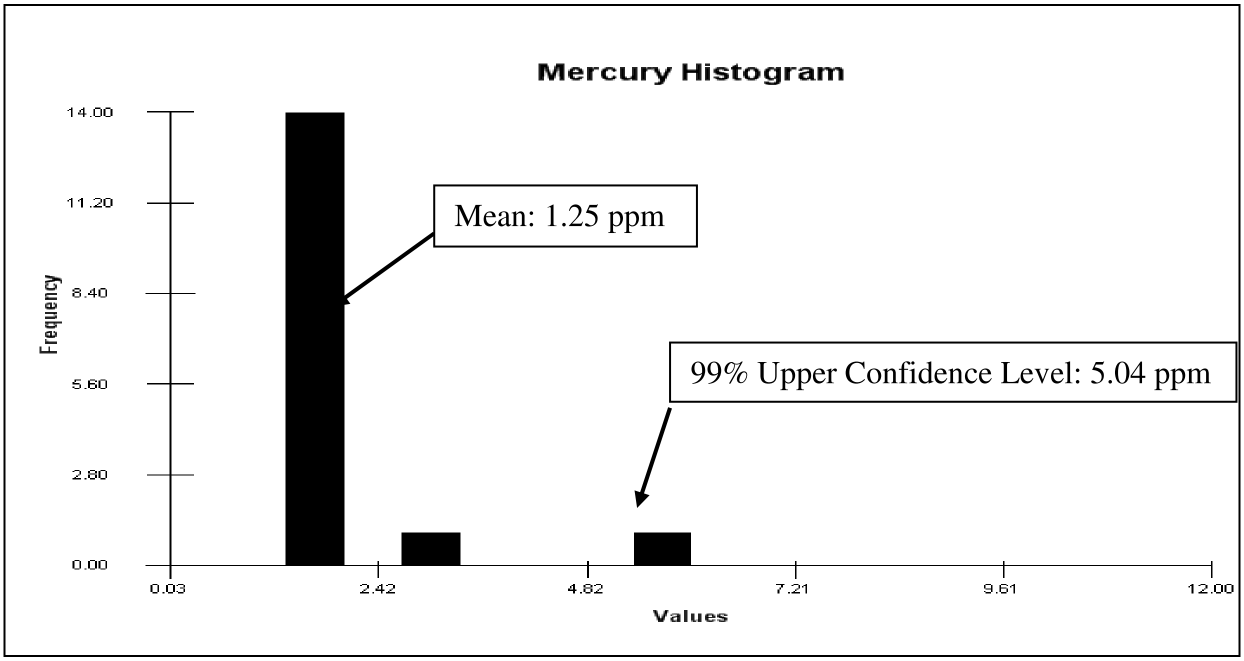


Figure 4. Mercury histogram

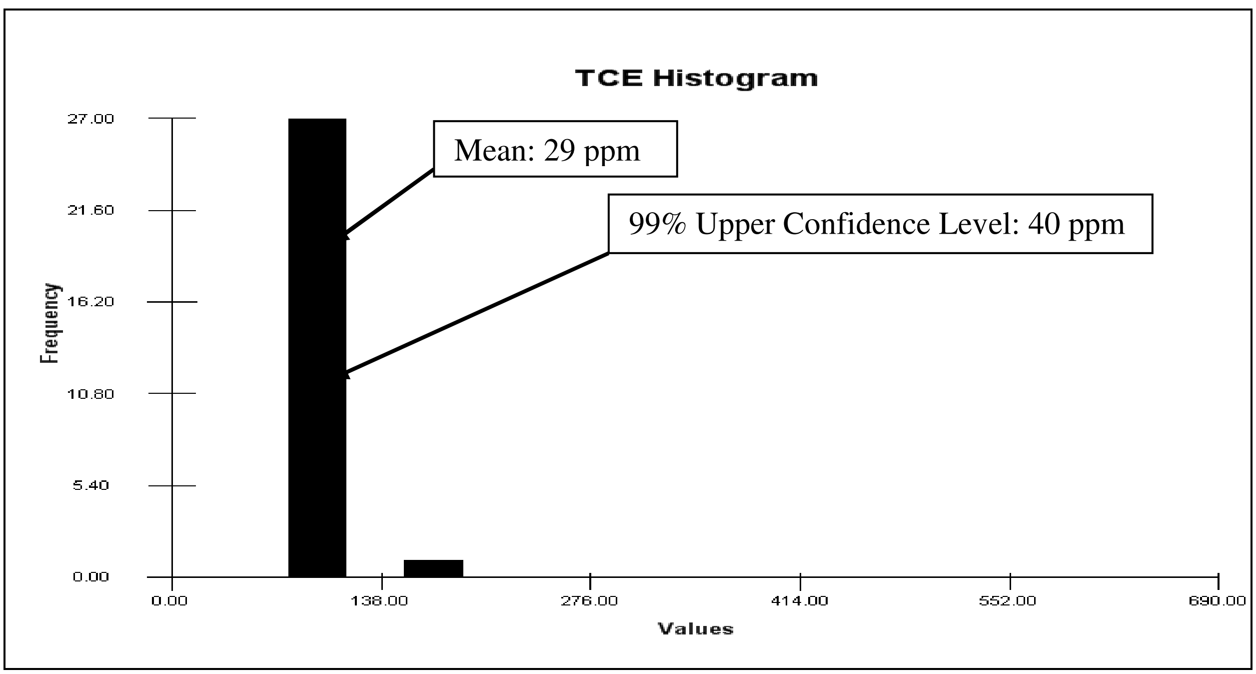


Figure 5. Trichloroethylene histogram

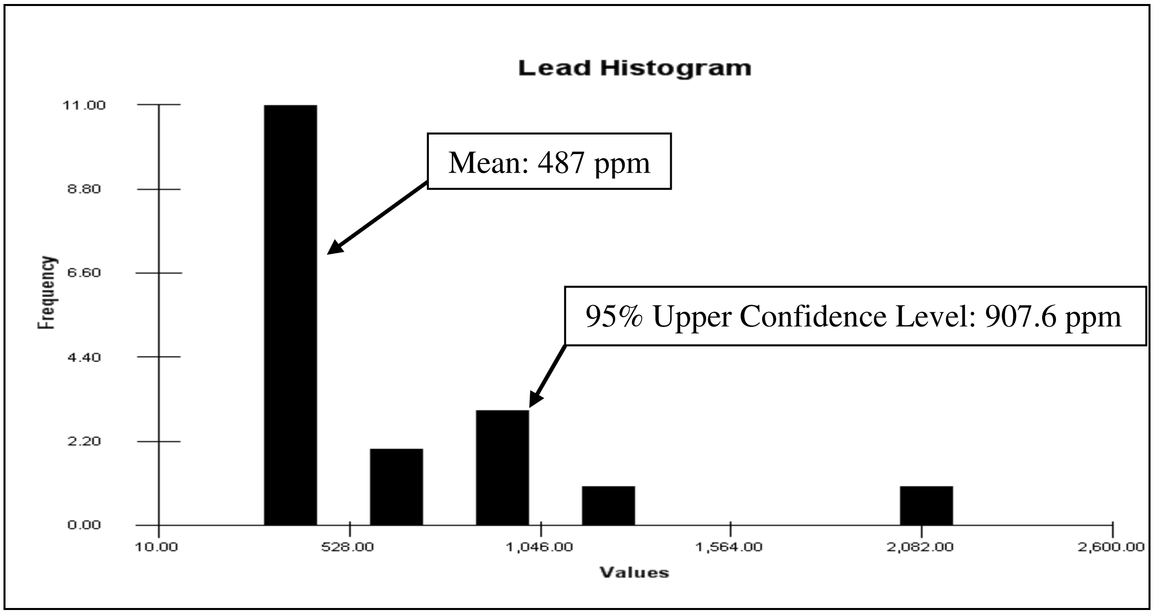


Figure 6. Lead histogram

B. **<u>Exposure Evaluation</u>**

1. **<u>General input values</u>**

As discussed earlier, a construction worker and a trespassing recreational person at the Site may be exposed to contaminated soil if the approximate one foot layer of soil at the Site is somehow breached during normal activity. Any recreational exposure is anticipated to be of short duration because it will be trespassing on-site for a short duration and child is assumed to be conservative due to their established limits and threshold are much lower than adults. Both populations are therefore assumed exposed to COCs in soil due to incidental inhalation of respirable particulates. It should be noted, according to USEPA guidance, the construction worker scenario is usually described as a short-term adult receptor who is exposed to soil contaminants during the work day for the duration of a single construction project (typically a year or less) (USEPA, 2001a). If multiple non-concurrent construction projects are anticipated, it is assumed that different workers will be employed for each project. The activities for this receptor typically involve substantial on-site exposures to surface and subsurface soils.

Soil inhalation risk equations in SADA are split into non-radionuclides (Equation 2; see Appendix A) and radionuclides (Equation 3; see Appendix A). Trichloroethylene, lead, and mercury are considered to be non-radionuclides and thus Equation 2 was used when determining our soil inhalation intake for the construction worker and recreational person scenarios. The construction workers population is assumed comprised of adults with a body weight of 70 kg (USEPA, 1991), an inhalation rate of 20 m^3/8 hr-day for moderate activity, (USEPA, 2001a), their exposure duration will be one year, with an exposure frequency of 225 days per year. In addition, a child under the recreational scenario is assumed to have an average bodyweight of 30 kg, be exposed for 6 years, and have an exposure frequency of 30 days per year (USEPA, 2001a). The input variables for Equation 2 are further described in Figures 1 and 2, Appendix B.

An evaluation was conducted using the risk based equations provided by SADA. SADA utilized the method developed by USEPA (USEPA, 1991) to estimate the permissible risk levels associated with the cleanup of contaminated soils to assess potential risks to construction workers and recreational persons during on-site potentially exposed to contaminated subsurface soils. This method provides for an assessment of overall risk combining contributions resulting from incidental inhalation.

2. **Calculating the chemical concentration term**

As described earlier the upper confidence level calculated by SADA does not appear to coincide with the data distribution and this is common in data sets originated from brownfield sites. For brownfield assessments, the concentration term in the intake equation is an estimate of the arithmetic average concentration for a contaminant based on a set of site sampling results. According to the USEPA, because of the uncertainty associated with estimating the true average concentration at a site, the 95% upper confidence limit (UCL) of the arithmetic mean should be used for this variable (USEPA 1996). The 95% UCL provides reasonable confidence that the true site average will not be underestimated.

As you increase the amount of sampling data collected you generally find uncertainties decrease and the UCL moves closer to the true mean. This is counterintuitive to Brownfield sites due to they generally consist of observations below detection limits and limited data sets; and our site is in no exception. The 95% UCL, accounts for uncertainties due to limited sampling data at brownfield sites.

In order to address the statistical issues; several statistical methods for data sets with non-detects have been assimilated into the statistical program approved by the USEPA known as ProUCL (Sing and Sing, 2007). These statistical methods help evaluate non-detects in the determination of upper confidence levels. In 2002, USEPA issued guidance for calculating the upper confidence levels of the unknown population means for contaminant concentrations at brownfield sites and ProUCL has served as companion software for the USEPA (2002b) guidance document for calculating UCLs. Initially, SADA determined the following 95% UCLs as displayed in Table VIII:

TABLE VIII

SADA DETERMINED UPPER CONFIDENCE LEVELS

Analyte	**Normal-Student's t 95% Upper Confidence Level**	**Lognormal- Land's H t 95% Upper Confidence Level**
Trichloroethylene	70	730
Lead	760	4100
Mercury	2.5	6.1

From the above results the major discrepancy in the proper UCL estimate is easily discern. It should be noted, that as discussed earlier, the number of observations for lead and mercury are low and this has a tendency to drive 95% UCL upwards. The Land's H method in particular has tendency to create extremely high 95% UCL, especially when there are not a lot of data and when the data are not symmetric. Hence this is why such high values from SADA were calculated. For this reason the current study used the

ProUCL statistical package to determine UCLs. The estimates in the following table were used to generate the soil inhalation intake for each scenario (Table IX).

TABLE IX

PROUCL DETERMINED UPPER CONFIDENCE LEVEL

Analyte	**Recommended Method**	**Upper Confidence Level**
Lead	95% Approximate Gamma Upper Confidence Level	907.6
Mercury	99% Chebyshev Upper Confidence Level	5.041
Trichloroethylene	95% Hall's Bootstrap Upper Confidence Level	791.3

ProUCL will identify the recommended 95% upper confidence level of the mean for the data set under evaluation. The result is identified as the "Recommended Method" on the output table. This is the 95% upper confidence level of the mean determined by ProUCL was inputted in to SADA as exposure variable related with the chemical specific soil concentration used for evaluation of the inhalation exposure pathway. However, we should further clarify each recommended method. The gamma upper confidence is the only upper confidence level which does not rely on the standard deviation of data. The Chebyshev method have a tendency to to deliver a conservative but realistic estimate of upper confidence level, especially sensitive to non-symmetrical data distribution which is common with brownfield sites.

Based on the results, the SADA exposure statistics were changed based on the appropriate UCL thus using the representative soil concentration value for each COC and thus allowing the calculation of the maximum soil intake for each scenario. The model was calibrated and distribution choices made for each contaminant, we calculated potential high risk areas in a brownfield site with the objective to protect construction workers and recreational persons.

For each of the potentially exposed populations, which in this case is construction workers and recreational persons, the total carcinogenic risk represents the excess likelihood of an individual developing some form of cancer over a lifetime as a result of the exposure scenario presented (CDC, 2009). Thus, a total carcinogenic risk for a population estimated at 1×10^{-6} can be understood as one excess chance in a million (1 chance in 1,000,000) for an individual member to develop cancer (USEPA, 2001b). The probability is stated as "excess" because there is a significant likelihood that any person will develop cancer in their lifetime. CDC (2009), currently estimates that one in three (1 in 3) people will develop cancer from all causes during their lifetime. Under the National Contingency Plan (NCP) (40 CFR §300.430(e)(2)), acceptable exposure levels for known or suspected carcinogens are generally concentrations levels that represent an excess upper-bound lifetime cancer risk to an individual of between 1×10^{-4} and 1×10^{-6} (USEPA, 2001b). A "point of departure" is defined as the dose-response point that marks the beginning of a low-dose extrapolation (USEPA, 1990). A risk level of 1×10^{-6} is specified as a point of departure in the NCP for determining remediation goals (USEPA, 1990).

The total hazard index calculated for each population is the indication as to whether an individual of the population is likely to experience any adverse non-cancer health effects (USEPA, 1990). For noncarcinogenic health effects, the risk assessment assumes there is a threshold value for concern (USEPA, 1990). Above the threshold value, there is concern that an individual may experience adverse non-cancer health effects; below the threshold, there is no known concern (USEPA, 1990). Consistent with the hazard evaluation methodology, adverse effects are only expected if a total hazard index exceeds a value of one (USEPA, 1990). Provided that the total hazard index for a population is less than one, no adverse non-cancer health effects are expected (USEPA, 1990). Based on this criterion, we were able to determine that trichloroethylene and mercury results were below the USEPA NCP total carcinogen risk point of departure and hazard quotients thresholds.

Based on the criterion concentrations exist on the Property that exceed the IEPA TACO Tier 1 Construction Worker Scenario Inhalation route SROs or USEPA SSLs. Thus presented below, Figures 7 to 9, display the high risk areas based on data from historical site investigations, prior to our involvement to the current study which is based on the SADA identified high risk areas.

To calculate these high risk areas SADA uses ordinary kriging. Instead of weighting nearby data points by some power of their inverted distance, ordinary kriging relies on the spatial correlation structure of the data to determine the weighting values. This is a more rigorous approach to modeling, as correlation between data points determines the estimated value at an unsampled point. These high risk areas maps serve as an important foundation for decision frameworks that determine cost and boundaries of the remedial process

Our high risk areas based on the historical investigation data had multiple unestimated points with no clear boundaries. The trichloroethylene high risk areas based on the historical investigation could not even generate a high risk area due to the lack of information. The high risk areas based on SADA display clear boundaries.

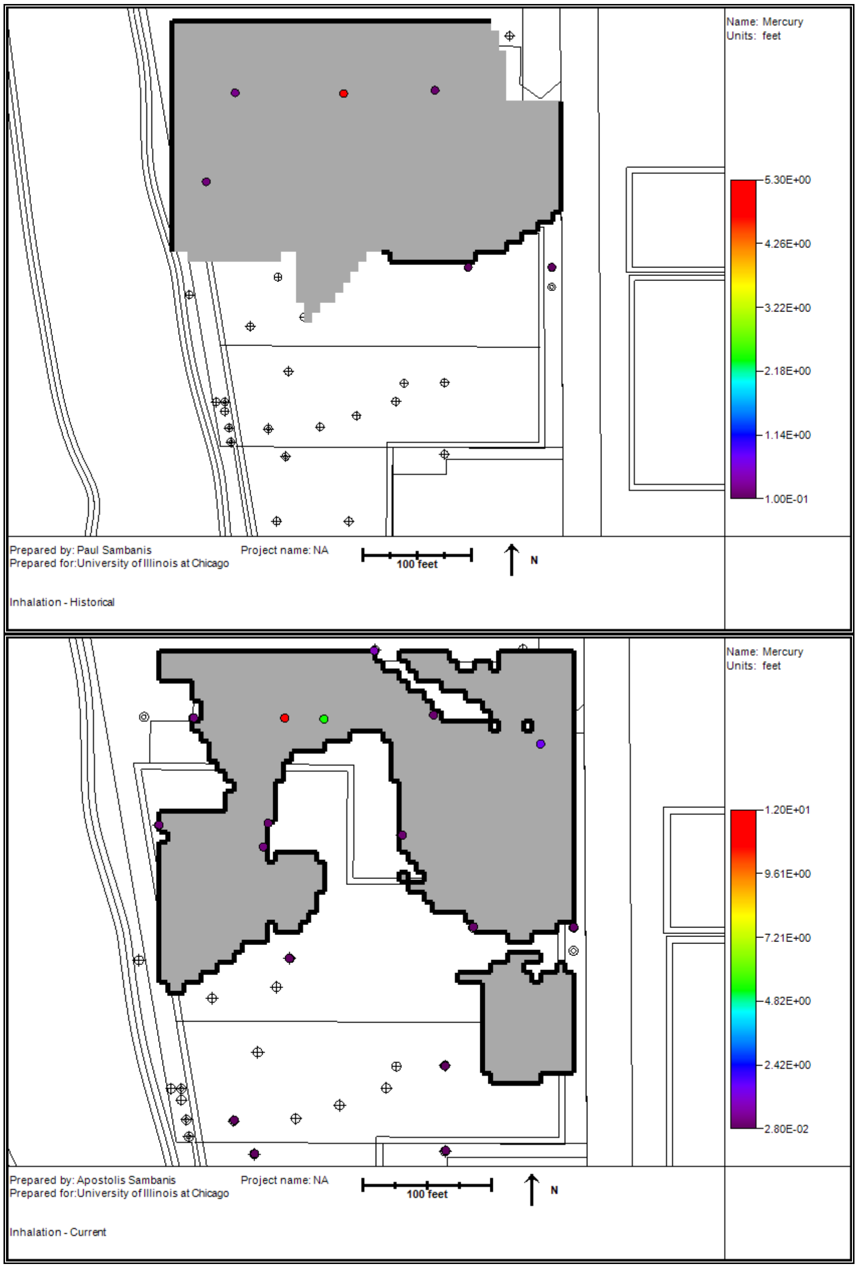


Figure 7. Construction worker inhalation high risk comparison (historical (top) vs. SADA identified (bottom) site investigations) to mercury exposure

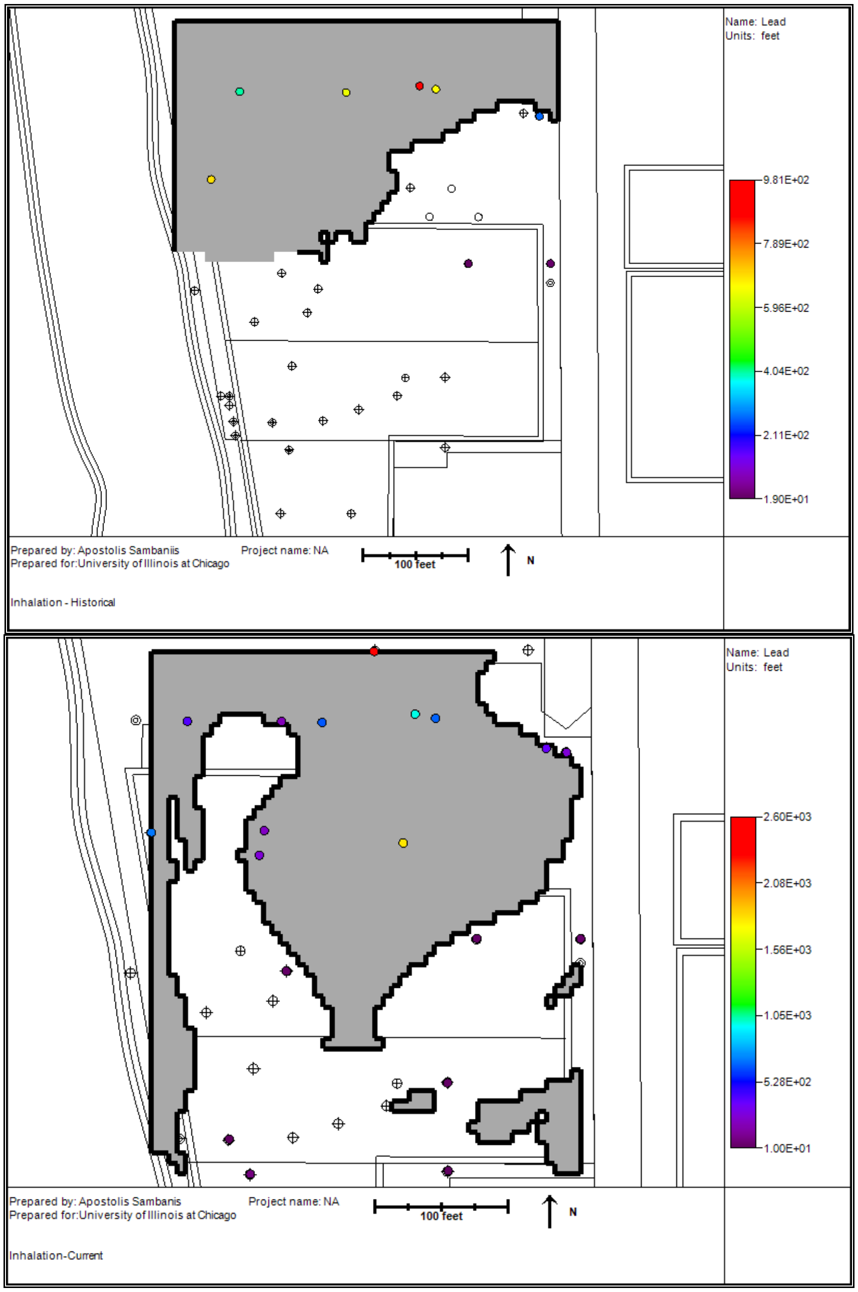


Figure 8. Construction worker inhalation high risk comparison (historical (top) vs. SADA identified (bottom) site investigations) to lead exposure

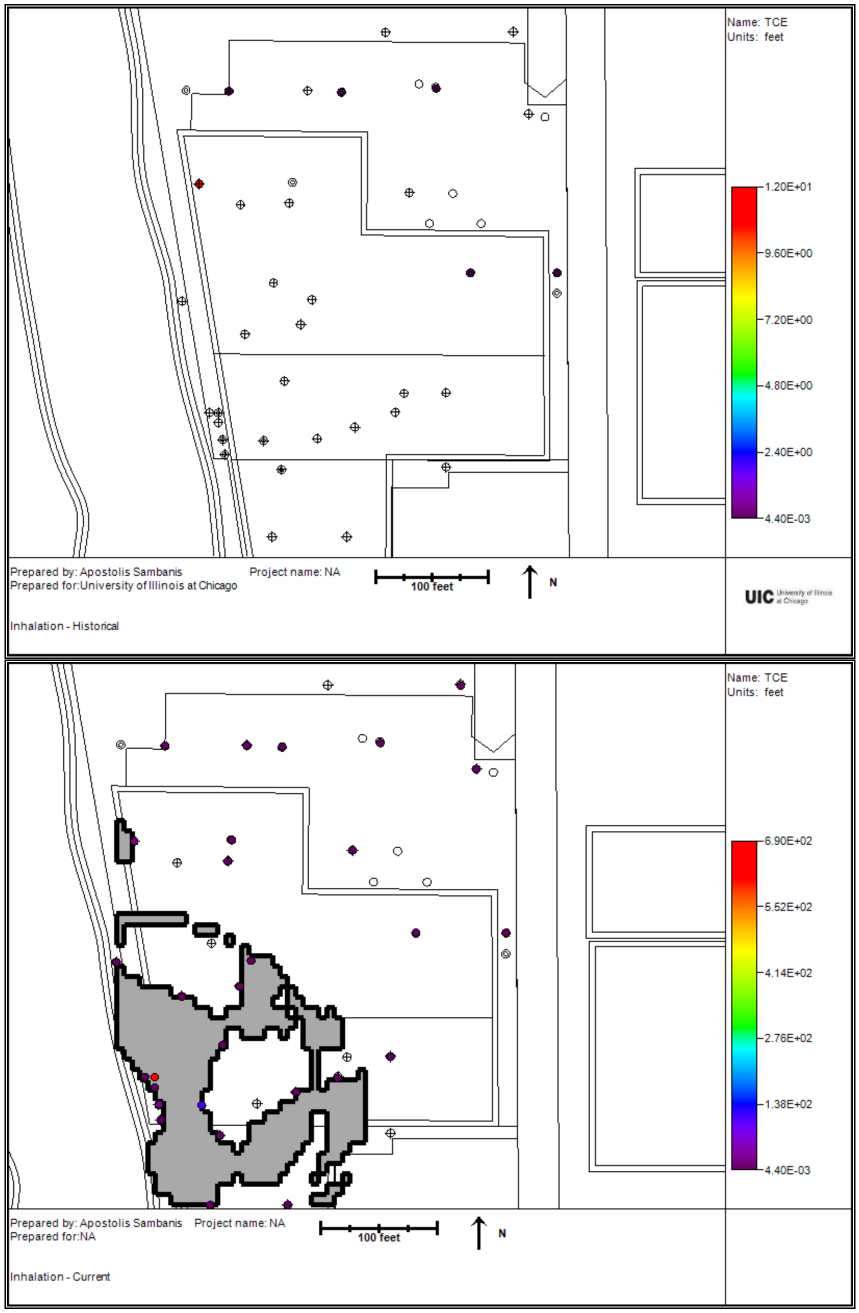
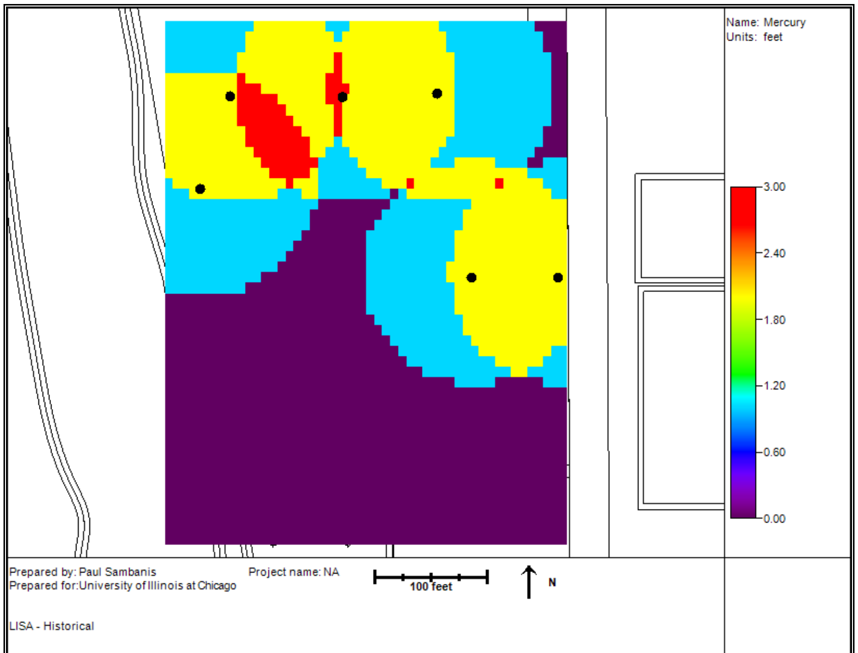


Figure 9. Construction worker inhalation high risk comparison (historical (top) vs. SADA identified (bottom) site investigations) to trichloroethylene exposure

C. **Hot Spot Evaluation**

After determining the high risk areas, an emphasis on the actual COC hot spots were determined. Discussed early Ripley's k provides information on the overall spatial distribution of the data and was used to determine our site sample design; Local Indicators of Spatial Association (LISA) provides information on types of spatial association at the local level. To clarify LISA maps indicate the presence or absences of significant spatial cluster or outliers for each sample locations. LISA maps are particular useful to identify local hot spots located on the Property. LISA maps (Figures 7 to 9) based on historical versus SADA identified site investigations.

LISA maps based on historical data show limited hot spots of the COCs all located on the north half of the Property. LISA maps based on the current study are justified by detection of increased concentration of COCs in the areas of red identified in Figures 10 to 12. In addition, the spatial distributions of the COCs are clear and easily estimated in the LISA maps based on the SADA identified investigation versus the historical site investigation.



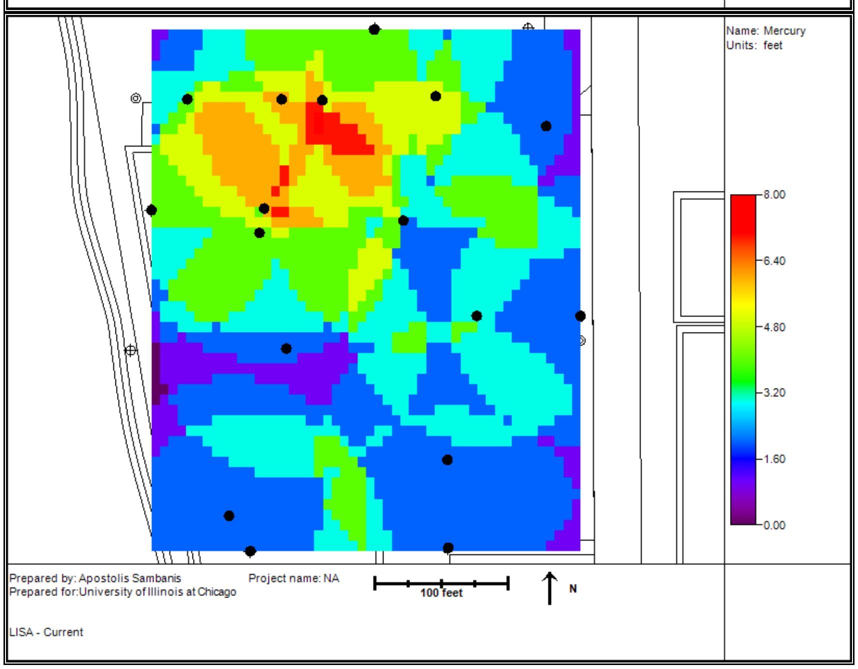


Figure 10. Hot spot comparison map of mercury contamination (historical (top) vs. SADA identified (bottom) site investigations)

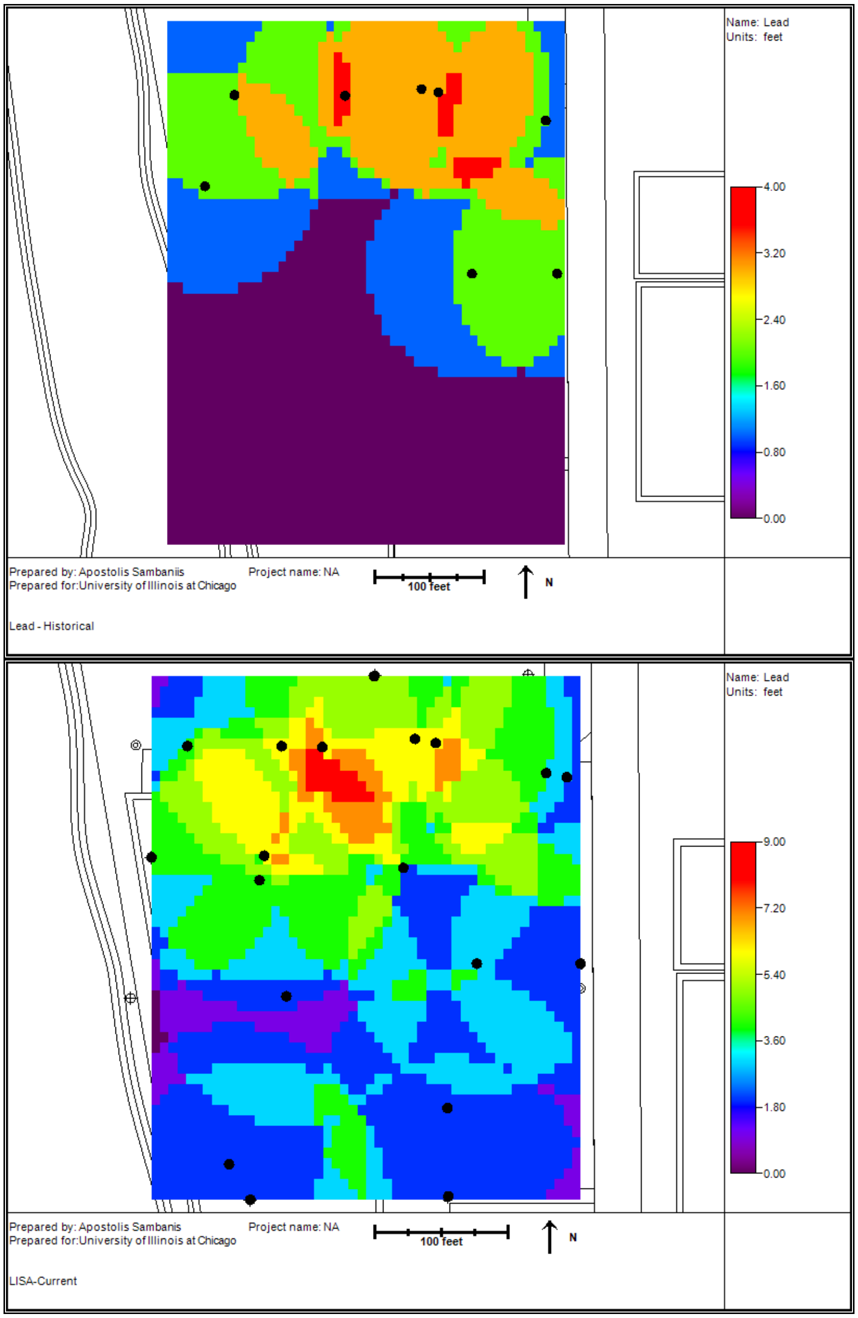


Figure 11. Hot spot comparison map of lead contamination (historical (top) vs. SADA identified (bottom) site investigations)

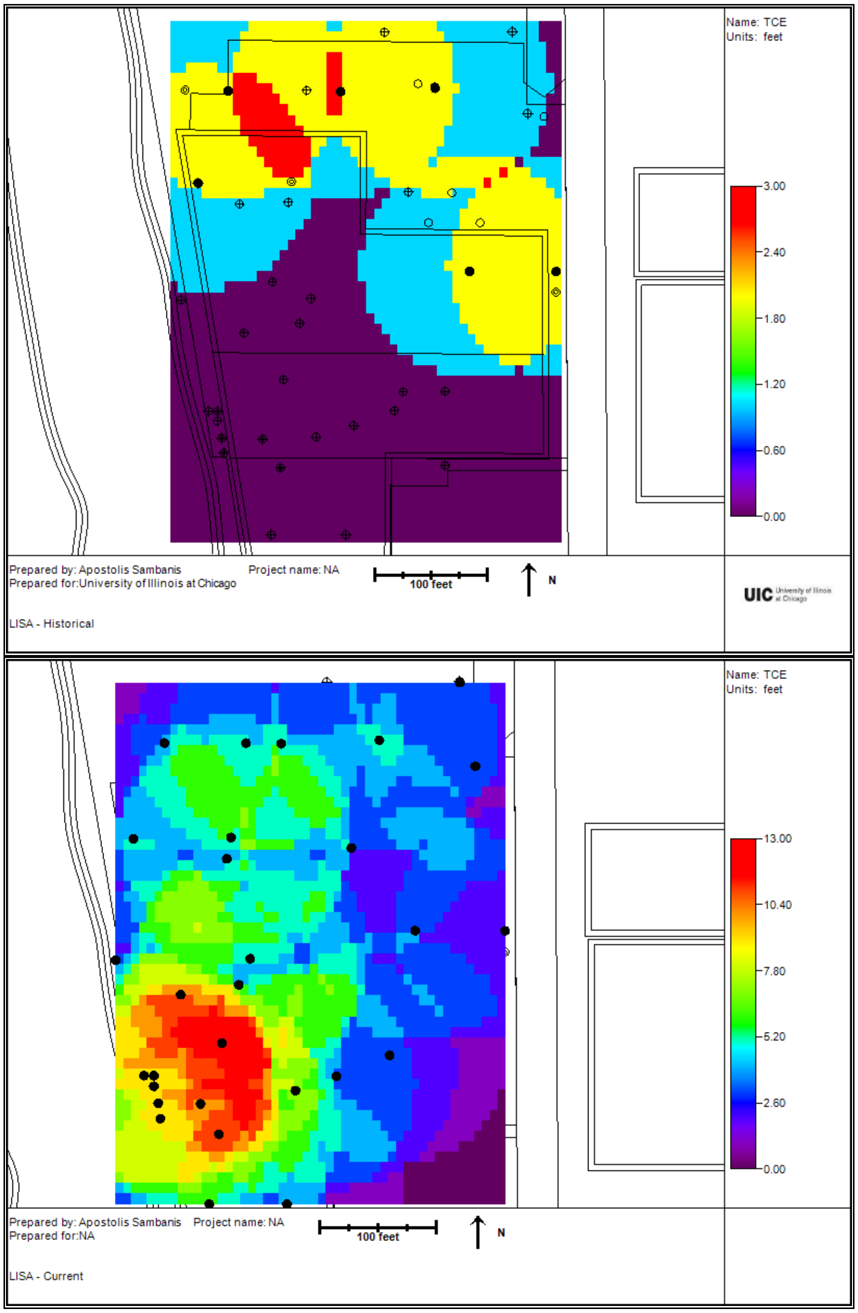


Figure 12. Hot spot comparison map of trichloroethylene contamination (historical (top) vs. SADA identified (bottom) site investigations)

D. **<u>Worker Restrictive Zones</u>**

After determination both the high risk areas and hot spots of the COCs, a need to regulate the worker restrictive zones was evident. Performing construction in areas of known site contamination has the possibility to increase project costs and construction worker exposure significantly. If soil is excavated to the depths within these high risk areas it will increase the probability of encountering contamination during construction and may require follow-up environmental investigation and reporting.

Using the SADA identified high risk areas of contamination, Figures 4 through 6, clean up restrictive zones for construction workers excavating in those areas were established (Figures 13 through 15). Consistent with hazardous waste operations, certain legal obligations are required to inform construction workers about the nature and level of hazardous substances at this site, and likely degree of exposure to workers who participate in site operations (Allan et al., 1996).

Thus, the purpose of characterization and creation of restrictive zones is to identify and quantify the health and safety hazards associated with each site task and operation, and stream lines with the legal obligations of each interested party (USEPA, 2001b). With this information presented below, Figures 10 to 12, risks are then eliminated if possible, or effectively controlled:

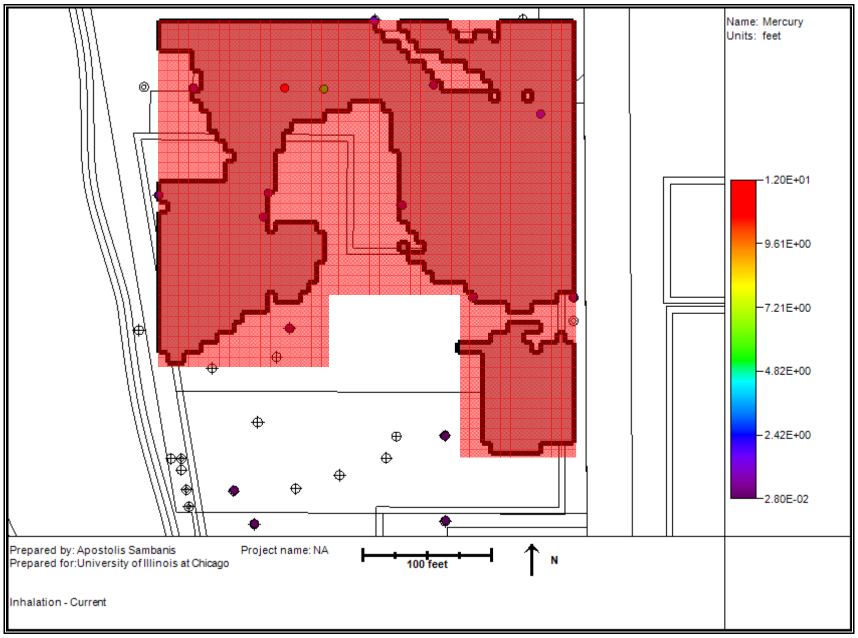


Figure 13. Construction worker restrictive zones for mercury exposure

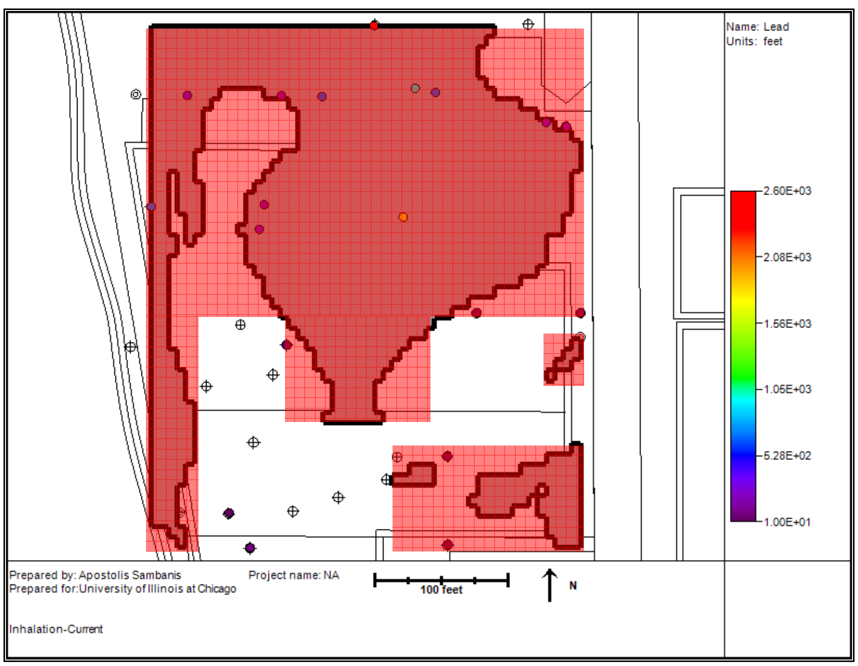


Figure 14. Construction worker restrictive zones for lead exposure

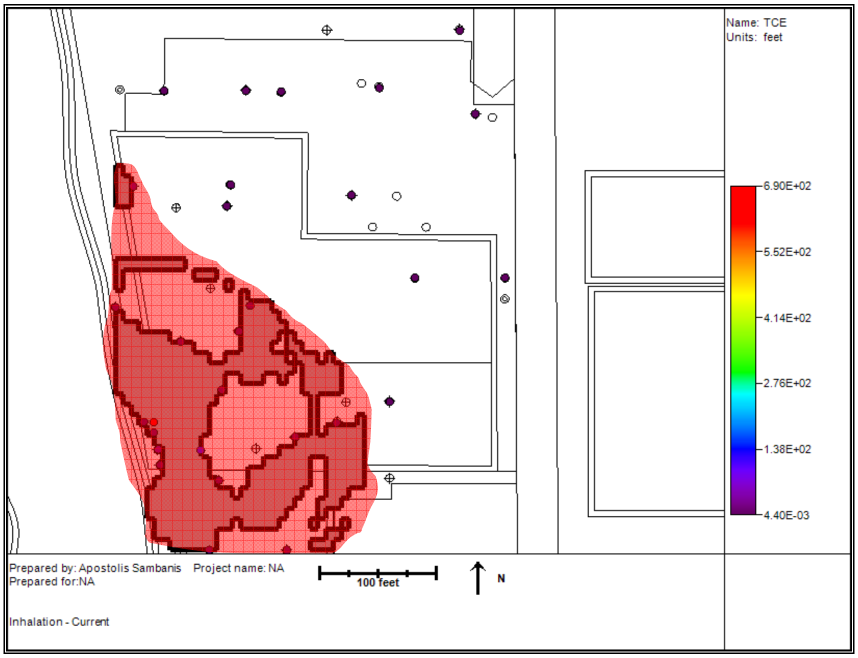


Figure 15. Construction worker restrictive zones for trichloroethylene exposure

Construction workers working within the red areas will be required to wear respirators with the appropriate cartridge based on the COC to minimize their potential exposure. This development of restrictive zones, using the high risk areas identified by SADA, is extremely useful for the development of site safety plans and help increase the efficiency by prioritize clean-up operations in brownfield redevelopment.

E. Comparison of Historical and SADA Identified Site Investigations

SADA was able to create a sample design based on historical site investigation results by interpolating between data points. As displayed in Table X, we compare the historical site investigation (prior to the use of SADA) versus the SADA identified site investigation (after the use of SADA).

TABLE X

COMPARISON TABLE

Historical Investigation	**Current Investigation**	**Comparison**
The maximum soil concentration detected was 12 mg/kg, 981 mg/kg, and 5.3 mg/kg for TCE, lead, and mercury soil concentrations.	The maximum soil concentration detected was 690 mg/kg, 2600 mg/kg, and 12 mg/kg for TCE, lead, and mercury soil concentrations.	Larger soil concentrations were identified in the current investigation.
The average soil concentration detected was 1.72 mg/kg, 468 mg/kg, and 0.894 mg/kg for TCE, lead, and mercury soil concentrations.	The average soil concentration detected was 26.9 mg/kg, 465 mg/kg, and 1.37 mg/kg for TCE, lead, and mercury soil concentrations.	The average soil concentration of the COCs was generally larger in the current investigation.
High risk areas of the COCs had large amounts of unestimated points and undefinable boundaries	High risk areas of the COCs had clear boundaries and little to no unestimated points	The high risk areas of the current investigation were able to create easily identifiable restictive zones for construction workers.
LISA maps identifed hot spots on the north side of the Property only and appears not to coincide with soil concentrations detected.	LISA maps identifed hot spots through out the Property and appears to coincide with soil concentrations detected.	The LISA maps of the current investigation were able to eaily identify the hot spots of the COCs.

SADA was able to compare to human health risk component and determine high risk areas based on construction worker land uses. The expected results for the manufacturing facility classified statically significant to actual results observed (i.e interpolated data computed results similar to actual results). The data captured from the SADA identified site investigation was useful to identify hotspots of COCs and create restrictive zones for construction worker. Thus, SADA has the ability be used in a range of public and private uses and is appropriate for brownfield redevelopment. However, it should be noted, special consideration needs to be accounted for when it comes the upper confidence levels used in soil concentration of each COC of the risk equations for SADA.

F. <u>Limitations of Study and Future Work</u>

Site characterization, assessment of potential exposures, the assessment of the toxicity of specific chemicals, and the characterization of risk are all in some respects uncertain. In characterizing a contaminated site, it is not possible to know with certainty the concentration of contaminants of concern at all locations. The characterization of any site involves the collection and analysis of soil or other samples that are of small volume compared with the overall site. Concentrations in other areas may vary. Methods used to increase the accuracy of site characterization usually include the selection of samples exhibiting the greatest qualitative indications of contamination, or the intentional collection of samples from areas where concentrations are expected to be the highest. In this study, the uncertainty of site characterization is countered by utilizing the highest concentrations for each contaminant of concern that was detected in the various samples collected at the site.

The assessment of potential exposures is uncertain because it is impossible to predict the behavior of all people who may work at or frequent selected areas of a contaminated site. Additionally, most of the methods used to assess potential exposures include assumptions regarding sensitive inputs. Uncertainties associated with exposure assessment are counter balanced by the use of conservative exposure assumptions. Examples of conservative exposure assumptions used in this assessment include the frequency and duration of potential exposures assumed for the exposed populations.

With respect to the assessment of toxicity, according to the USEPA, describe the confidence levels and uncertainties associated with the present understanding of the adverse human health effects associated with specific chemicals (USEPA, 1989 and 1991). Because toxicity data are partly uncertain, USEPA counter balances uncertainty with upper-bound estimates of central tendency. For example, carcinogenic slope factors are 95th percentile estimates of potency (USEPA, 2001c). This assessment further counters the uncertainty of toxicity by treating all exposures faced by a single population as additive, even in cases where contaminants of concern pose risks associated with different mechanisms of effect. Adverse health effects resulting from different toxicity mechanisms are not, in fact, usually additive. Specific uncertainties relating to the assessment of toxicity include the lack of toxicity parameters for the carcinogenic properties of lead and mercury, both of which are considered possible human carcinogens. The lack of useable toxicity values for these specific compounds tends to diminish the estimates of total risk stated herein.

The final steps of the study, characterizing restrictive zones, includes all of the uncertainties and counter balancing conservative assumptions inherent to the site characterization, assessment of potential exposures, and the quantitative statements of toxicity used in the equations to provide numeric estimates of risk. Because of the uncertainties inherent to the overall study, total carcinogenic risk and total hazard indices for the potentially exposed populations are expressed to only one significant figure. As a result, the numeric values for risk included in this study should be considered order of magnitude estimates, subject to the uncertainties and assumptions stated herein. Although this study includes uncertainty, I believe that the uncertainties associated with the study are effectively offset by the inherently conservative assumptions included for many of the inputs.

To improve the future of the program we suggest that the statistical calculation of the upper confidence level should be reevaluated. Data distributions vary greatly and choosing the correct upper confidence level is indeed critical as discussed earlier. Thus, SADA should look in to adapting a similar model to the ProUCL program which runs the data through several types of upper confidence level methods and recommends the proper method to be used.

IV. CONCLUSIONS

The results of the study point to the usefulness of the program as it applies to public health. Specifically, able to complete the following objectives of this study as listed below:

- To demonstrate the use of SADA to identify sampling locations by taking into account previous studies as well as potential polluting sources;
- To evaluate the applicability of SADA for the selection of samples based on financial constraints;
- To assess the applicability of SADA for the identification of potential high risk areas in a brownfield site with the objective to protect construction workers and trespassing recreational persons; and,
- The use of SADA to prioritize clean-up operations and creation of restrictive zones.

The computer program was able to create a sample design based on historical site investigation results by interpolating between data points. The expected results for the brownfield site classified statically significant to actual results observed (i.e interpolated data computed results similar to actual results).

SADA was able to compare to human health risk component and determine high risk areas based on construction worker land uses. The data captured from the SADA identified site investigation was useful to identify hotspots of contaminants of concern and create worker restrictive. Thus, SADA has the ability be used in a range of public and private uses and is appropriate for brownfield redevelopment.

APPENDICIES

APPENDIX A
EQUATIONS

$$\hat{K}(h) = \frac{\sum_{i=1}^{N} \sum_{j=1(j \neq i)}^{N} w_{ij} I(h_{ij} \leq h)}{\lambda N}$$

Where $\lambda = N/|A|$
N is the number of samples,
A is the area of the site
w_{ij} is the spatial weight used to account for edge effects near the boundary
h_{ij} is the euclidean distance between the ith and jth points in a data set of n points

Equation 1. Ripley's K Method – Retrieved from SADA documentation (2008)

$$Nonrad\ Intake_{inh} = \frac{C_{sn}\, EF\, ED \left(\frac{1}{VF} + \frac{0.036\,(1-V)(U_m / U_t)^3 F(x)}{(Q/C)\, CF_3} \right) IR_{air}}{CF_2\, BW\ AT}$$

Equation 2. Soil Inhalation Non-Radionuclides Equation – Retrieved from SADA documentation (2008)

$$Rad\ Intake_{inh} = C_{sr}\, CF_5\, EF\, ED \left(\frac{1}{VF} + \frac{0.036\,(1-V)(U_m / U_t)^3 F(x)}{(Q/C)\, CF_3} \right) IR_{air}$$

Equation 3. Soil Inhalation Radionuclides Equation – Retrieved from SADA documentation (2008)

APPENDIX B
FIGURES

Parameter	Units	Residential	Industrial	Recreational	Agricultural
Non-radionuclide chemical concentration in soil = C_{sn}	mg/kg	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific
Radionuclide chemical concentration in soil = C_{sr}	pCi/g	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific
Exposure frequency = **EF**	day/year	350 (EPA 1989a)	250 (EPA 1991a)	40 (EPA 1992)	350 (EPA 1989a)
Exposure duration = **ED**	years	30 (EPA 1989a)	25 (EPA 1991a)	30 (EPA 1989a)	30 (EPA 1989a)
Conversion factor = $\mathbf{CF_5}$	g/kg	1000	1000	1000	1000
Volatilization factor = **VF**	m^3/kg	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific
Fraction of vegetative cover = **V**	unitless	0.5 (EPA 1996)	0.5 (EPA 1996)	0.5 (EPA 1996)	0.5 (EPA 1996)
Mean annual windspeed = $\mathbf{U_m}$	m/s	4.69 (EPA 1996)	4.69 (EPA 1996)	4.69 (EPA 1996)	4.69 (EPA 1996)
Equivalent threshold value of windpeed at 7 m = $\mathbf{U_t}$	m/s	11.32 (EPA 1996)	11.32 (EPA 1996)	11.32 (EPA 1996)	11.32 (EPA 1996)
Function dependent on $\mathbf{U_m/U_t}$= **F(x)**	unitless	0.194 (Cowherd 1985)	0.194 (Cowherd 1985)	0.194 (Cowherd 1985)	0.194 (Cowherd 1985)
Inverse of the mean concentration at the center of a 0.5 acre-square source = **Q/C**	(g m^3)/ (m^2 s kg)	90.8 (EPA 1996)	90.8 (EPA 1996)	90.8 (EPA 1996)	90.8 (EPA 1996)
Seconds in an hour = $\mathbf{CF_3}$	s/h	3600	3600	3600	3600
Total inhalation rate = $\mathbf{IR_{air}}$	m^3/day	20 (EPA 1989a)	20 (EPA 1989a)	6.7 (8 hours) (EPA 1992)	20 (EPA 1989a)
Conversion Factor = $\mathbf{CF_2}$	days/yr	365	365	365	365
Body weight = **BW**	kg	70 (adult) (EPA 1991a)	70 (adult) (EPA 1991a)	70 (adult) (EPA 1991a)	70 (adult) (EPA 1991a)
Lifetime = **LT**	years	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)
Averaging time = **AT**	years	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)

Figure 1. Default values for equations – Retrieved from SADA documentation (2008)

APPENDIX B (continued)

FIGURES

Scenario[1]	Residential	Non-Residential (Commercial/Industrial)		Construction	
Receptor	On-site Resident[2]	Outdoor Worker	Indoor Worker	Construction Worker	Off-site Resident
Exposure Frequency (d/yr)	350	225	250	site-specific	site-specific
Exposure Duration (yr)	30 [6 (child)[4] for non-cancer effects]	25	25	site-specific	site-specific
Event Frequency (events/d)	**1**	1	NA	1	NA
Soil Ingestion Rate (mg/d)	200 (child) 100 (adult)	100	50	330	NA
Ground Water Ingestion Rate[3] (L/d)	2	2	2	NA	NA
Inhalation Rate (m^3/d)	20[5]	20	20	20	20
Surface Area Exposed (cm^2)	**2,800 (child) 5,700 (adult)**	3,300	NA	3,300	NA
Adherence Factor (mg/cm^2)	**0.2 (child) 0.07 (adult)**	0.2	NA	0.3	NA
Body Weight (kg)	15 (child) 70 (adult)	70	70	70	70
Lifetime (yr)	70	70	70	70	70

1 This exhibit presents information on simple site-specific soil screening evaluations for three exposure scenarios -- residential, commercial/industrial, and construction. Additional exposure scenarios (e.g., agricultural and recreational) may be appropriate for certain sites. Given the lack of generic information available for these scenarios, site managers will typically need to use detailed site-specific modeling to develop SSLs for them.

2 Items in bold represent changes to the residential soil screening exposure scenario presented in the 1996 *SSG*.

3 SSLs for the migration to ground water pathway are based on acceptable ground water concentrations, which are, in order of preference: a non-zero Maximum Contaminant Level Goal (MCLG), a Maximum Contaminant Level (MCL), or a health-based level (HBL) based on a 1 x 10^{-6} incremental lifetime cancer risk or a hazard quotient of one due to ingestion of contaminated ground water. When an HBL is used, it is based on these ground water ingestion rate values.

4 A child is defined as an individual between one and six years of age.

5 We evaluate residential inhalation exposure to children and adults using the RfC toxicity criterion, which is based on an inhalation rate of 20 m^3/day. No comparable toxicity criterion specific to childhood exposures is currently available. EPA has convened a workgroup to identify suitable default values for modeling childhood inhalation exposures, as well as possible approaches for adjusting toxicity values for application to such exposures.

Figure 2. Default values for equations based on construction worker scenario – Retrieved from USEPA documentation (2002a)

CITED LITERATURE

Allan, H., Sciortino, S., Goeden, H., & Wright, C.: Consideration of background exposures in the management of hazardous waste sites: a new approach to risk assessment. Risk Analysis 16(5); 619-625: 1996.

ATSDR (Agency for Toxic Substances and Disease Registry). Toxicological Profile for Mercury. ATSDR/U.S. Public Health Service. 1989.

ATSDR (Agency for Toxic Substances and disease Registry). Toxicological Profile for Lead. Update. Prepared by Clement International Corporation under contract No. 205-88-0608 for ATSDR, U.S. Public Health Service, Atlanta, GA. 1993.

ATSDR (Agency for Toxic Substances and Disease Registry). Toxicological Profile for Trichloroethylene. ATSDR/U.S. Public Health Service. 1997.

Centers for Disease Control and Prevention (CDC). Public health assessment, rsr corporation. Agency for Toxic Substances and Disease Registry, Atlanta, GA: 2009.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, Pub. L. No. 96-510, 94 Stat. 2767. 1980.

Chicago Metropolitan Agency for Planning (CMAP) Brownfield Redevelopment Strategy. Available via http://www.cmap.illinois.gov/strategy-papers/brownfields. Cited January 13, 2008.

Clark, Philip; Evans, Francis (1954). "Distance to nearest neighbor as a measure of spatial relationships in populations". Ecology (Ecological Society of America) 35 (4): 445–453

Coffin, Sarah L and Barbero, Colleen. Making Connections in the Brownfield Marketplace. Environmental Practice, 11 , pp 170-178. 2009.

Cowherd, C., G. Muleski, P. Engelhart, and D. Gillete. 1985. Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination. Prepared for EPA Office of Health and Environmental Assessment. EPA/600/8-85/002.

Illinois Environmental Protection Agency. Title 35: Environmental Protection. Subtitle G: Waste Disposal, Chapter I: Pollution Control Board, Part 742: Tiered Approach to Corrective Action Objectives. Illinois Statutes, Springfield, IL. 1997.

Knowlton, Robert G. and Minier, Jeffrie. Recent Trend for Environmental Compliance Provides New Opportunities for Land and Water Use at Brownfields and Other Contaminated Sites. Natural Resources Journal, Vol. 41, No. 4. 2001.

Layman, R.H. and Northrup C.J. Survey of Illinois Law: Environment; 22 S. Ill. U. L. J. 879. 1998.

Leigh N, Coffin S. How Many Brownfields Are There? Building an Industrial Legacy Database. Journal of Urban Technology, Vol. 7, Iss. 3. 1-18. 2000.

McCarthy L. The brownfield dual land-use policy challenge: reducing barriers to private redevelopment while connecting reuse to broader community goals. Land Use Policy, Volume 19, Number 4, pp. 287-296(10). 2002.

Murphy M. The Impact of Superfund and Other Environmental Statutes on Commercial Lending and Investment Activities. 41 Bus. Law. 1133. 1986.

Ruiz-Esquide A. The Uniform Environmental Covenants Act-An Environmental Justice Perspective. 31 Ecology L.Q. 1007. 2004.

Powell, Frona M. Amending CERCLA to Encourage the Redevelopment of Brownfields: Issues, Concerns, and Recommendations; 53 Wash. U. J. Urb. & Contemp. L. 113. 1998.

Ripley, B. 1977. Modelling spatial patterns (with Discussion). J. R. Stat. Soc. Ser. B Methodol. 39: 172–212.

Schenck, D. The Next Step for Brownfields: government Reinsurance of Environmental Cleanup Policies. Connecticut Insurance Law Journal, 10: 2004.

Sing, A., and A.K. Sing, 2007. ProUCL Version 4.0Technical Guide. EPA/600/R-07/041. US Environmental Protection Agency Office of Research and Development, Washington, DC, USA.

Small Business Liability Relief and Brownfields Revitalization Act, H.R. 2869, 107th Cong. (2001), enacted as Pub. L. No.107–118.

Spatial Analysis and Decision Assistance. University of Tennessee, United States. Available via http://www.tiem.utk.edu/~sada/index.shtml. Cited January 13, 2008.

Simon W.H. The Community Economic Development Movement: Law, Business, and the New Social Policy. pp 1-6. 2001.

U.S. Environmental Protection Agency. Risk assessment guidance for Superfund volume I: human health evaluation manual (Part A). EPA/540/1-89/002. U.S. Environmental Protection Agency, Washington, DC 20460: 1989.

U.S. Environmental Protection Agency. The revised hazard ranking system: an improved tool for screening superfund sites. Publication 9320.7-01FS. Office of Solid Waste and Emergency Response. U.S. Environmental Protection Agency, Washington, DC 20460: 1990.

U.S. Environmental Protection Agency. Role of the baseline risk assessment in superfund remedy selection decisions. OSWER 9355.0-30. Office of Emergency and Remedial Response. U.S. Environmental Protection Agency, Washington, DC 20460: 1991.

U.S. Environmental Protection Agency. Hazard ranking system guidance manual. Publication 9345.1-07. Office of Solid Waste and Emergency Response. U.S. Environmental Protection Agency, Washington, DC 20460: 1992.

U.S. Environmental Protection Agency. Superfund program representative sampling guidance volume 1: soil interim final. EPA 540/R-95/141 PB96-963207. Office of Emergency and Remedial Response. U.S. Environmental Protection Agency, Washington, DC 20460: 1995a.

U.S. Environmental Protection Agency. Establishing background levels. PB94-963313. Office of Emergency and Remedial Response. U.S. Environmental Protection Agency, Washington, DC 20460: 1995b.

U.S. Environmental Protection Agency. Soil screening guidance: technical background document. Office of Solid Waste and Emergency Response. U.S. Environmental Protection Agency, Washington, DC 20460: 1996.

U.S. Environmental Protection Agency. Lead; identification of dangerous levels of lead; final rule. (40 CFR Part 745). Washington DC: 2001a.

U.S. Environmental Protection Agency. Risk assessment guidance for superfund: volume 1 human health evaluation manual (part d, standardized planning, reporting, and review of superfund risk assessments. Publication 9285.7-47. Office of

Emergency and Remedial Response. U.S. Environmental Protection Agency, Washington, DC 20460: 2001b.

U.S. Environmental Protection Agency. Guidance for characterizing background chemicals in soil at superfund sites external review draft. OSWER.9285.7-41. Office of Emergency and Remedial Response. U.S. Environmental Protection Agency, Washington, DC 20460: 2001c.

U.S. Environmental Protection Agency. Supplemental guidance for developing soil screening levels for SUPERFUND sites OSWER 9285.6-07P. Office of Solid Waste and Emergency Response. U.S. Environmental Protection Agency, Washington, DC 20460: 2002a.

U.S. Environmental Protection Agency. Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites OSWER 9285.6-10. Office of Emergency and Remedial Response. U.S. Environmental Protection Agency, Washington, DC 20460: 2002b.

U.S. Environmental Protection Agency. Basic Information.[online].[Last update July 6th, 2006]. Available from:< http://www. epa.gov/brownfields/basic_info. htm> Cited January 13, 2012. 2006.

U.S. Environmental Protection Agency. Child-specific exposure factors handbook, EPA/600/R–06/096F. National center for environmental assessment, Office of research and development, US environmental protection agency, Washington, DC 20460, September 2008.

U.S. Environmental Protection Agency. National priorities list. Retrieved from http://www.epa.gov/superfund/sites/npl/index.htm: October 21, 2010a.

U.S. Environmental Protection Agency. Superfund risk assessment. Retrieved from http://www.epa.gov/oswer/riskassessment/risk_superfund.htm: January 22, 2010b.

U.S. Environmental Protection Agency. Mid-atlantic risk assessment - frequently asked questions. Retrieved from http://www.epa.gov/reg3hwmd/risk/human/rb-concentration table/faq.htm#FAQ1: December 2, 2010c.

U.S. Environmental Protection Agecny. Mid-atlantic risk assessment user's guide. Retrieved from http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/usersguide.htm: January 1, 2011.

VITA

NAME:	Apostolis Stefanos Sambanis
EDUCATION:	B.S., Earth and Environmental Science, University of Illinois at Chicago, Chicago, Illinois, 2007
TEACHING:	Environmental and Occupational Health Science Division, University of Illinois at Chicago, 2011-2012
EXPERIENCE:	Regulatory Administrator, True Value Company, November 2011 to Present
	Project Geologist, Weaver Boos Consultants, July 2008 to November 2011
	Staff Geologist, Environmental Resources Management, December 2006 to July 2008
	Laboratory Technician, University of Illinois at Chicago Organic Geochemistry Laboratory, August 2004 to December 2006